ISBN: 978-93-48620-68-2

RESEARCH TRENDS IN FOOD SCIENCE AND TECHNOLOGY

EDITORS:
DR. ANKITA SHAMA
MISS. ATHULYA SOJAN
MRS. K. NITHIYA
DR. SHRIKANT VERMA

Bhumi Publishing, India
First Edition: February 2025

Research Trends in Food Science and Technology

(ISBN: 978-93-48620-68-2)

Editors

Dr. Ankita Shama

Subject Matter Specialist,

Agriculture University,

Jodhpur, Rajasthan

Miss. Athulya Sojan

Department of Food Science and

Agricultural Chemistry,

McGill University, Montreal, Canada

Mrs. K. Nithiya

Department of Mental Health Nursing,

Sri Manakula Vinayagar Nursing College,

Kalitheerthalkuppam, Puducherry

Dr. Shrikant Verma

Department of Personalized and

Molecular Medicine,

Era University, Lucknow, U.P.

Bhumi Publishing

February 2025

Title: Research Trends in Food Science and Technology

Editors: Dr. Ankita Shama, Miss. Athulya Sojan, Mrs. K. Nithiya, Dr. Shrikant Verma

First Edition: February 2025

ISBN: 978-93-48620-68-2

Published by:

Bhumi Publishing

BHUMI PUBLISHING

Nigave Khalasa, Tal – Karveer, Dist – Kolhapur, Maharashtra, INDIA 416 207

E-mail: bhumipublishing@gmail.com

PREFACE

Food science and technology play a pivotal role in shaping the future of global food security, nutrition, and sustainable production. As scientific advancements continue to evolve, research in this field integrates diverse disciplines, including microbiology, biotechnology, chemistry, engineering, and nutrition, to enhance food safety, quality, and innovation. This book, Research Trends in Food Science and Technology, presents a comprehensive overview of the latest developments, emerging technologies, and future prospects in this ever-expanding domain.

This volume brings together cutting-edge research from scholars and experts who address key aspects such as food preservation, novel processing techniques, functional foods, food safety regulations, and sustainable food production. By bridging traditional knowledge with modern technological interventions, this book aims to provide valuable insights into improving food quality, extending shelf life, and addressing global challenges like food waste and malnutrition.

A major focus of this book is to highlight interdisciplinary approaches that foster innovation in food science and technology. From the role of nanotechnology in food packaging to advancements in alternative protein sources, this compilation explores groundbreaking research that has significant implications for the food industry, policymakers, and consumers alike.

We extend our sincere gratitude to all the contributing authors, researchers, and reviewers whose valuable efforts have made this publication possible. Special thanks are also due to the editorial team and institutions supporting this endeavor. It is our hope that this book serves as an essential resource for academicians, industry professionals, and students, inspiring further research and development in food science and technology.

We invite readers to explore the latest trends and discoveries presented in this book and to contribute to the ongoing advancements that will shape the future of food science.

- Editors

TABLE OF CONTENT

A STUDY ON BREAKFAST CONSUMPTION AND NUTRITIONAL STATUS OF ADOLESCENT GIRLS

A. Jeevarathinam*, M. Maha lakshmi, V. Malarvizhi, S. Manimala and R. Murugananthi

Department of Home Science,

V. V. Vanniaperumal College for Women, Virudhunagar, Tamil Nadu

*Corresponding author E-mail: jeevsrathi@gmail.com

Abstract:

Breakfast is said to be vital for sustaining the physical and mental health of an individual. A human being's daily nutritional requirements centred around breakfast. Breakfast as the first meal of the day is one of the most skipped meals by adolescent students. This investigation was carried out to ascertain the breakfast pattern and health conditions of the girls studying at colleges in and around Virudhunagar. The data was collected by survey method. It was found that the hostel and day scholar students skipped their breakfast. It was also found that both the students suffering from obesity, underweight, over weight problems. At least 10.71% of students have body mass index. So, this study concluded that a nutritional awareness programme was needed to improve the nutritional status of adolescent girls.

Introduction:

The simple definition of breakfast is "the first meal of the day, " which is consistent with the etymology of "break" the "fast". It is simply identified as "the first meal of the day, consumed within 2 hours of waking, before starting daily activities (Mohiuddin, 2019). The main part of a person's daily dietary needs is breakfast. Individuals who consume cereal for breakfast every day claim to feel less anxious, unhappy, and mentally troubled. Skipping breakfast has been linked to negative consequences for a variety of mental and physical health issues. People who neglect breakfast consume a smaller amount of a variety of vitamins, minerals, and nutrients since they are unable to make up for their missing nutrients at any other time of the day. Unfortunately, more people skip breakfast than any other meal, yet it's crucial significantly to both dietary quality and general health (Kalpana Agrahari *et al.,* 2017). Those who skipped breakfast or ate an inadequate breakfast are 68% more inclined to develop metabolic syndrome as adolescents.

Unhealthy eating habits are an important contributor to a lifetime risk of acquiring chronic diseases. Breakfast is recommended to contain 20%–35% of daily energy needs (Timlin *et al.,* 2007), It is considered the most important meal of the day as a part of a healthy balanced diet (Marangoni *et al.,* 2009). Breakfast habits are significantly associated with physiological, psychological, and social health dimensions (Chen *et al.,* 2014). Several studies reported associations between breakfast skipping and fatigue at noon, worsened memory and higher body mass index as well as increased prevalence of obesity-related chronic illness (Mekary *et al.,* 2012); deficient in total energy, vitamins and minerals, increased risk of central adiposity, and risk of insulin resistance and cardio-metabolic disorders. If the stomach is kept empty for a long time, the body will suffer a deficiency of proteins and glucose. Then blood sugar will drop down followed by mood swings (Moschiano *et al.,* 2012).

Not only breakfast, skipping a meal often creates harm to health, although fasting has its advantage which is ritual in many religions. A healthy breakfast but not a heavy breakfast is highly recommended. Those who are in a rush can take a protein-rich low-volume diet. Protein shakes as an alternative to breakfast is a common practice in many Western countries but this discussion is not within the scope of this article. Skipping meals for IBS and gastroenteritis may find little benefit but no study ever pointed to skipping breakfast for those issues. A healthy breakfast is different for different people based on age, sex, living style and physical activities. School/University students should never miss breakfast causes they badly need a jumpstart of energy for the day. Diabetic people should keep in mind that the same is important for them to sensitize insulin release. Rich or poor, young or elderly, all must have a healthy refreshment in the morning for an energized and enthusiastic day start.

Anthropometrics can be sensitive indicators of infant and child health, growth, and development. In particular, anthropometry has been used during adolescence in many contexts related to nutritional status (WHO, 1985 and 2002; Bose and Mukhopadhyay, 2004). According to the World Health Organization, the ultimate intention of nutritional assessment is to improve human health (Beghin *et al.,* 1988). Malnutrition (undernutrition or overnutrition), which refers to an impairment of health either from a deficiency, excess, or imbalance of nutrients, is of public health significance among adolescents worldwide. It creates lasting effects on a person's growth, development, and physical fitness. It is well-recognized worldwide that anthropometric measurements are indispensable in diagnosing undernutrition. It has now been well established that the body mass index (BMI) is the most appropriate variable for determining nutritional status among adolescents (WHO, 1985)In India 33.8% adolescents of Aligarh (New Delhi) do not take their breakfast regularly, The rates of breakfast skipping range from 10% to 30% amongchildren in.In japan based on national dietary survey saysthat the skipping breakfastaverages 14% men and 9% in women among adolescents, whereas 18% among children (HeatherJ, 2013). Skipping breakfast among children in North America is16% and 18% for adolescents. In Korea59.1% of children and 34.1% of adolescent skipping breakfast.

Meal skipping is the omission or lack of consumption of one or more of the traditional main meals (breakfast, lunch, or dinner) throughout the day. The regular omission of meals, particularly the breakfast meal, has been associated with poorer diet quality, lower intakes of total energy, vitamins and minerals increased risk of central adiposity, markers of insulin resistance and cardiometabolic risk factors. Estimated prevalence rates of meal skip-ping in the young adult population vary between 24 and 87%, with young adults consistently reporting higher rates of meal skipping compared with other age groups.

Adolescents are at particularly high risk of health-compromising behaviour, such as increased fast food consumption, increased sedentary levels and frequent breakfast skipping. Getting adequate exercise and sleep, maintaining a healthy weight, not smoking or binge drinking, and eating breakfast regularly, decline dramatically in the transition to young adulthood (Frech, 2012). College eating habits and lifestyles can add pounds of weight to students (Racette, 2005). Fast food consumption and breakfast skipping increased during the transition to adulthood, and both dietary behaviours are associated with increased weight gain from adolescence to adulthood. These behaviours may be appropriate targets for intervention during this important transition (Niemeier *et al.,* 2006). Skipping breakfast can cause a range of health problems for children, contribute to poor academic performance and can even cause behavioural problems in the classroom (Rachel, 2014).

Regular breakfast consumption among adolescents has been linked with improved cognitive function, better dietary intake, and healthful weight status. Youth who consume breakfast tend to have a lower body mass index (BMI) and less excess weight gain (Merten *et al.,* 2009). The evidence on the association of breakfast consumption with body weight in the European population has been collected in the systematic review published in 2010; collectively, the data from observational studies carried out in Europe until 2009 have consistently demonstrated that children and adolescents who eat breakfast have a reduced risk of becoming overweight or obese and have a lower Body Mass Index (BMI) compared with those who skip breakfast (Szajewska *et al.,* 2010). Moreover, a series of studies have reported that breakfast skipping is associated with hypertension, cardiometabolic disease, insulin insensitivity, diabetes mellitus, and mortality (Smith, 2010).

This study was carried out to find out the pattern and nutritional status of college students while keeping these factors in consideration. The study's goal is

- to figure out teenage females' breakfast preferences.
- to identify the cause of teenage girls skipping breakfast.
- to assess adolescent females' nutritional scenario based on their body mass index.

Methodology

Selection of Area

The present study was conducted in and colleges in Virudhunagar district.

Selection of Students

The students were chosen at random based on their residence status (50 percent were day scholars and 50 percent were hostel students).

Preparation of Questionnaire

Breakfast customs have been recognised since the Middle Ages, but the significance of breakfast as an element of a balanced diet has only recently been emphasised. Breakfast may be seen from several perspectives and from a variety of expertise, but the increasing scientific knowledge on this topic is highly sector-based. The subjects that were chosen were asked about their breakfast skipping habits. The purpose of the questionnaire was to collect data on eating habits, breakfast skipping patterns and frequency, alternative breakfast items, and other related topics.

Details of the Study

The student's education details were collected to know which degree they studying.

Dietary Habit

Dietary habits are the daily preferences that individuals or groups of people adopt regarding the foods they consume. The students were requested to keep track of what they were eating.

Breakfast Skipping Pattern

Even while breakfast customs have been understood since the Middle Ages, the importance of breakfast as a component of a balanced diet has only lately been emphasised. Although the growing amount of scientific knowledge on the matter is primarily sector-based, breakfast could be seen from a variety of perspectives and with varying levels of expertise. The chosen students were asked about their breakfast skipping habits. Additionally, they were asked how frequently they skipped breakfast, the food they consumed on its stead, and other facts, all were recorded through the questionnaire.

Anthropometric Measurement

Changes in physical parameters are known as anthropometric measurements. Anthropometric measurements therefore serve as helpful standards for evaluating the state of nutrition. The Body Mass Index, or BMI, was obtained utilising the anthropometric data, including height (cm) and weight (kg), which were gathered during the course of the questionnaire.

Collection of Data

The questionnaires were sent to selected students in Google form through their mail id.

Statistical analysis

The collected data were analyzed with the help of the following way

Percentage %=n//N x100

n =number of respondents N=Total number of observations

Result and discussion

Educational details of the selected students were tabulated in the table 1.

Table 1: Education details of the selected students

Class	% of students
UG students	85.19%
PG students	14.81%

This result indicated that majority of students studying UG degree responded to this survey eagerly.

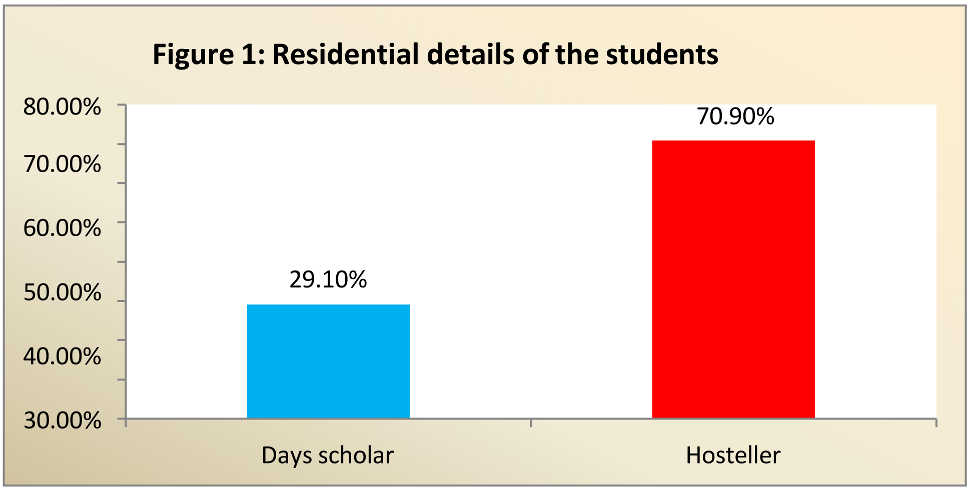
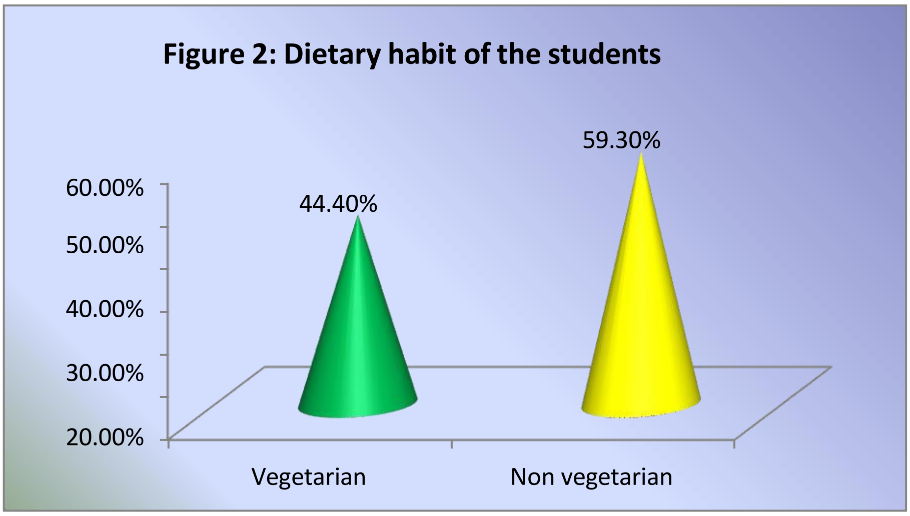
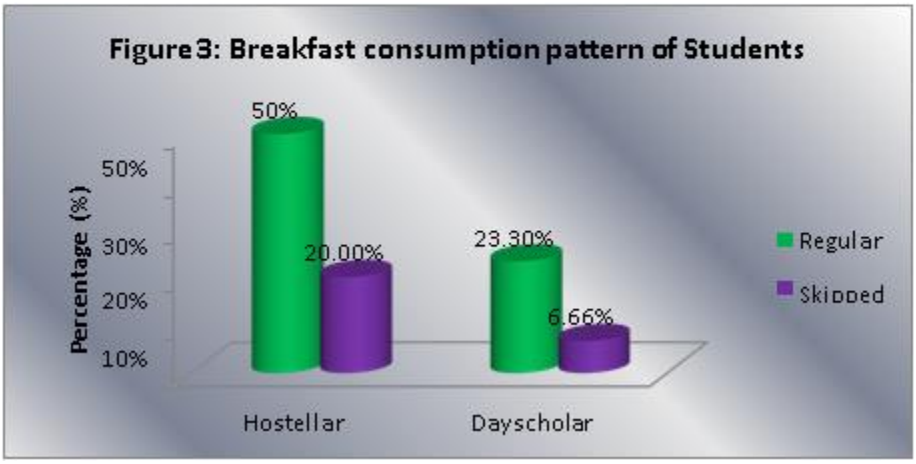


Figure 1 shows that maximum 70.90% of respondents were resident in hostel inside the college, while 29.10% of respondents were day scholar.



According to the figure 2 59.30% of the girls were Non vegetarians and the remaining 44.40% were vegetarians.

Breakfast consumption pattern of the participants shown in the figure 3.



From the figure it was found that a greater percentage of the hostel students (20%) omitted their breakfast when compared to the day scholars (6.66%). This is also indicated that 50% hostel students and 23.3% Day scholar students have taken the breakfast regularly. The pattern of breakfast meal consumption of participants showed that, the hostel students more skipped their breakfast than the day scholar students.

Table 2 indicates the frequency of breakfast skipping among the chosen participants.

Table 2: Frequency of breakfast skipping among students

Time Intervals for breakfast skipping	Frequency of skipping (%)
Daily	7.4%
Weakly Once	25.9%
Weakly Twice	3.7%
Monthly Twice	7.4%
Never	55.6%

Among the students, about 7.4% of the students skipped their breakfast daily, 5.9% skipped once per week, 3.7% missed every week twice and 7.4% omitted twice per month. Difficulties faced when skipping breakfast were also analyzed. Students were asked to answer how they feel when they skip their breakfast. 60% of students answered they couldn't concentrate on their class, 12.5% of students felt hungry and tired during class hours and 15% of students felt sick.

Table 4: Reason for breakfast skipping

Factors	% of Respondent
Do not like the food	44.4%
No time to eat	22.2%
No time to prepare	7.4%
Enrotronal disturbance	18.5%
Reduie the weight	14.8%

Table 4 reveals that the factors influence the skipping of breakfast by the students. It was found that the 44.4% of students skipped their breakfast because they do not like the food, 22.2% of students due to the lake of time for breakfast, 18.5% of students due to emotional disturbance and 14.8 % of students skipped their breakfast to reduce their weight. Least 7.4 % of students skipped their breakfast because they have no time to prepare for themselves.

This study also reveals that the breakfast skippers taken mid morning snacks like 26.6% of students consumed fruits, 3.33% of students consumed snacks from canteen or home and 6.66% of students taken juice/cool drink as mid morning snacks. But 53.3% students directly consumed lunch after skipped their breakfast.

Figure 5: Foods preferred by the students

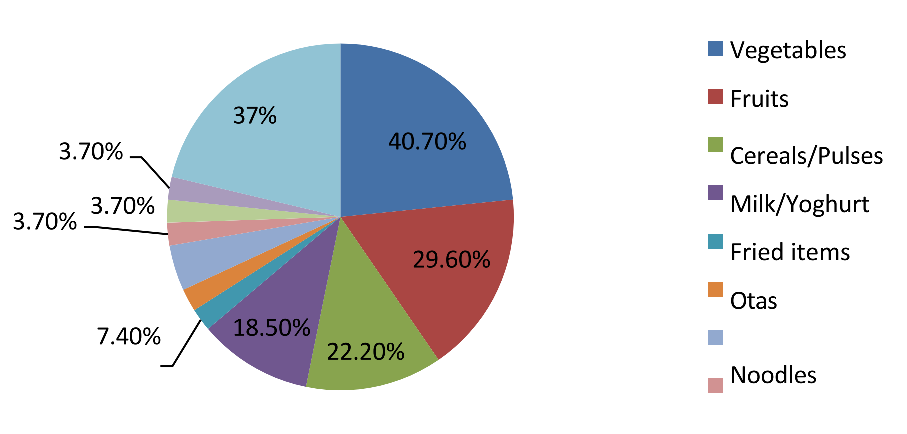
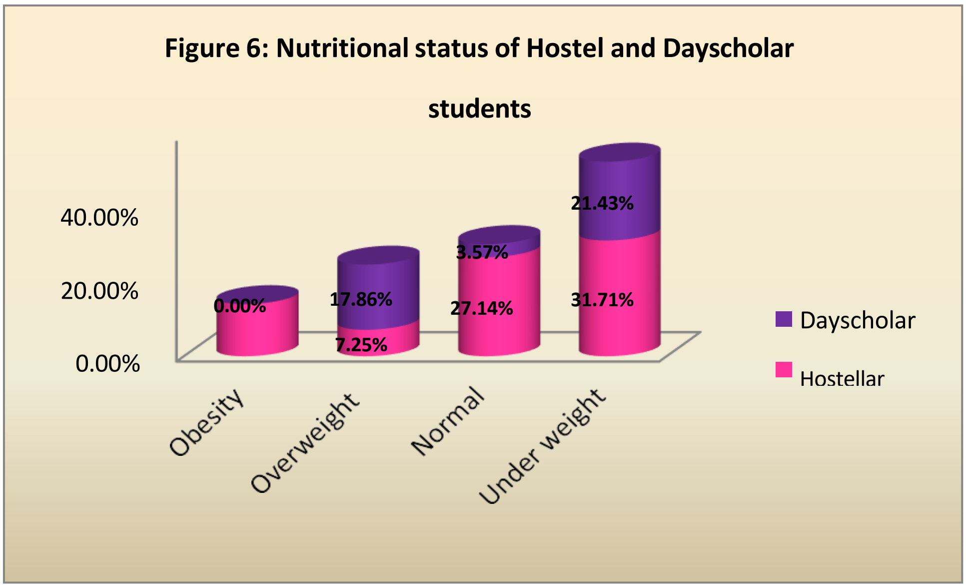


Figure 5 shows that maximum 40.70% of students were preferred to consume greenleafy vegetables per day as breakfast. The result also reveals that the students didn't prefer millets in their breakfast.

Table 5: Body mass index values of college students

Body mass index (kg/m^2)	Classification	Percentage of Students
>25.0	Obesity	14.29%
23-24.9	Overweight	42.86%
18.0-22.9	Normal	10.71%
<18	Underweight	32.14%

In the present study 32.14% students suffered from Underweight, 42.86% adolescent girls were overweight and only 10.71% girls had normal nutritional status.



The results given in figure 6 revels that the both day scholar and hostel students suffering by overweight, under weight problems. It was also found that the 27.14% of Hostel students had normal weight.

Conclusion:

The present study concluded that breakfast skipping is common among the students who are the pillars of our nation. Skipping breakfast causes poor nutritional status of the youngsters. There is a need to reduce the breakfast skipping to prevent the life style diseases among the youngsters. Regular consumption of breakfast improves the health status of adolescents and makes their future bright. So adolescents are encouraged to take meals regularly at time and consume more healthy foods.

References:

1. Mohiuddin, A. K. (2019). Skipping breakfast everyday keeps well-being away. *Acta Medica*, *50*(1), 26-33.
2. Beghin, I., Cap, M., Dujardin, B., & World Health Organization. (1988). *A guide to nutritional assessment*. World Health Organization.
3. Bose, K., & Mukhopadhyay, A. (2004). Nutritional status of adolescent Bengalce boys. *Indian pediatrics*, *41*(6), 633-636.
4. Chen, J., Cheng, J., Liu, Y., Tang, Y., Sun, X., Wang, T., ... & Zhao, X. (2014). Associations between breakfast eating habits and health-promoting lifestyle, suboptimal health status in Southern China: a population based, cross sectional study. *Journal of Translational Medicine*, *12*, 1-10.

5. Frech, A. (2012). Healthy behavior trajectories between adolescence and young adulthood. *Advances in life course research*, *17*(2), 59-68.
6. Leidy, H. J. (2013). The benefits of breakfast consumption to combat obesity and diabetes in young people. *American Journal of Lifestyle Medicine*, *7*(2), 99-103.
7. Agrahari, K., Agrahari, K., & Mishra, S. (2017). A study on breakfast consumption pattern and eating habits of youth of Sultanpur City.
8. Marangoni, F., Poli, A., Agostoni, C., Di Pietro, P., Cricelli, C., Brignoli, O., ... & Paoletti, R. (2009). A consensus document on the role of breakfast in the attainment and maintenance of health and wellness. *Acta Biomed*, *80*(2), 166-171.
9. Mekary, R. A., Giovannucci, E., Willett, W. C., van Dam, R. M., & Hu, F. B. (2012). Eating patterns and type 2 diabetes risk in men: breakfast omission, eating frequency, and snacking. *The American journal of clinical nutrition*, *95*(5), 1182-1189.
10. Moschiano, F., Messina, P., D'Amico, D., Grazzi, L., Frediani, F., Casucci, G., ... & Bussone, G. (2012). Headache, eating and sleeping behaviors and lifestyle factors in preadolescents and adolescents: preliminary results from an Italian population study. *Neurological Sciences*, *33*, 87-90.
11. World Health Organization(1985) *Measuring nutritional status*. World Health Organization, Geneva.
12. Racette, S. B., Deusinger, S. S., Strube, M. J., Highstein, G. R., & Deusinger, R. H. (2005). Weight changes, exercise, and dietary patterns during freshman and sophomore years of college. *Journal of American college health*, *53*(6), 245-251.
13. Smith, K. J., Gall, S. L., McNaughton, S. A., Blizzard, L., Dwyer, T., & Venn, A. J. (2010). Skipping breakfast: longitudinal associations with cardiometabolic risk factors in the Childhood Determinants of Adult Health Study. *The American journal of clinical nutrition*, *92*(6), 1316-1325.
14. Szajewska, H., & Ruszczyński, M. (2010). Systematic review demonstrating that breakfast consumption influences body weight outcomes in children and adolescents in Europe. *Critical reviews in food science and nutrition*, *50*(2), 113-119.
15. Timlin, M. T., & Pereira, M. A. (2007). Breakfast frequency and quality in the etiology of adult obesity and chronic diseases. *Nutrition reviews*, *65*(6), 268-281.
16. World Health Organization. (2003). *Adolescent friendly health services: an agenda for change* (No. WHO/FCH/CAH/02.14). World Health Organization.

INVESTIGATING THE STRUCTURAL PROPERTIES OF COTTON FIBERS FOR FOOD PACKAGING AND SUSTAINABLE AGRICULTURE

Manju V V* and Vinayakaprasanna N Hegde

Vidyavardhaka College of Engineering,

Gokulam, 3rd Stage, Mysuru, India -570002

*Corresponding author E-mail: manjuvv@vvce.ac.in

Abstract:

The molecular structure and elastic properties of various cotton fibres, including MCU-5, LRA, Shankar, Suvin, and Kodai, was thoroughly analysed to explore their suitability for food packaging applications. The Linked Atom Least Square (LALS) method was used to calculate the elastic constants, leveraging Wide-Angle X-ray Scattering (WAXS) data obtained from these selected cotton fibres. This method provided detailed insight into the fibres' crystalline structure and mechanical behaviour. The results revealed that the cotton fibres exhibit a monoclinic unit cell with the space group P21, indicating specific molecular orientations and symmetries. These structural characteristics are essential for understanding the fibres' stiffness, flexibility, and overall strength. By assessing the elastic properties, it becomes possible to predict how cotton fibres would perform under different stress conditions, which is crucial for their use in food packaging. The knowledge of their molecular and elastic properties aids in optimizing the fibres for biodegradability and sustainability. This analysis is key to improving cotton fibres' performance as eco-friendly alternatives to synthetic materials. Ultimately, this study highlights the potential of MCU-5, LRA, Shankar, Suvin, and Kodai cotton fibres to contribute to sustainable food packaging solutions. The findings pave the way for future innovations in biodegradable materials that can reduce environmental impact.

Keywords: XRD; Cotton; LALS; Elastic Constants, Food Science

Introduction:

In the textile industry, cotton is called the “king of fibres”. Cotton is belonging to “Gossypium” family. It is very much fluffy soft, staple fibre and cultivates in a capsule around the seed of cotton plant. It comes under “seed fibres” category due to fibres of cotton are produced in a capsule situated around cotton seeds. Among natural fibres, more than 90% are having vegetable origin, in which cotton contributes more than 80%. Due to its high air permeability, cotton fabric is extremely popular for its property of "breathability" [1]. Each cotton lint is made up of concentric layers, the longitudinal structure of cotton consists of base, body and the tip. The cross-sectional structure involves cuticle, primary wall, winding layer, secondary wall, lumen wall and lumen [1]. The chemical composition of cotton fibre includes (91-94%) of cellulose, (6-8%) of water, (0.5-1%) of waxes and fats, (1-1.5%) of proteins, (0.5-1%) of protoplasm and pectin's, and (0.2-1%) of mineral salts [1]. Botanically there are four commercially important cotton species are identified such as hirsutum, barbadense, aboreum, and herbaceum [2]. These imperative breeds include many varieties developed using breeding methods to grow improved quality of fibres such as increasing yield, increasing of disease resistance, increasing of strength and uniformity etc. Gossypium hirsutum is a tetraploid cotton, this breed mainly grown in the region of United States of America. These varieties also called American Upland cotton. Among the world production of cotton, Upland cotton provides 90% of present world production. The staple length of these cottons varies from 22-36 mm and the value of micronaire vary from 3.8-5. These breeds of fibres are widely utilized for industrial products, apparel and home furnishings. Gossypium barbadense is also a tetraploid cotton, which has an origin of South America, it provides longest staple length that is greater than 35 mm. The micronaire value will be less than 4. This breed supplied total 8% of raw fibre for the world production of cotton fibre. Gossypium aboreum and herbaceum are also diploids cotton fibres, these are also termed as "Desi" cottons. The staple length of these fibres ranges from 9.5-19mm, the micronaire value will be greater than 6. These fibres are commercially grown in the countries of India, China and Pakistan [2]. The raw cotton fibre after mechanical cleaning and ginning is almost 90% of cellulose, the non-cellulosic constituents of cotton located in primary wall, and in the lumen. In addition to conventional grown of cotton fibres, now a day's extensive research is undergoing to produce new hybrids and contemporary biotechnology to develop biotech cotton fibres [3, 4] which increase the production flexibility.

Materials and Methods:

1. Sample Collection

This study focuses on the cotton fiber varieties MCU-5, LRA, Shankar, Suvin, and Kodai, which were sourced from the University of Agricultural and Horticultural Sciences, Shivamogga, India, following the ginning process for further analysis. MCU-5 originates from a pedigree of Gatooma, Sea Island-542, MCU-1, and MCU-2. LRA cotton is a crossbreed of Laxmi, Reba B.50, and AC 122. Shankar is developed from G. Dot 100 and G. Cot 100.

Suvin traces its lineage to St. Vincent and Sujata cotton, while Kodai is derived from the Gossypium hirsutum family.

2. X-ray Diffraction Studies

X-ray diffraction (XRD) is a widely used technique for analysing the structural properties of single-crystal, semi-crystalline, and polycrystalline materials. In this study, five cotton fibre varieties—MCU-5, LRA, Shankar, Suvin, and Kodai—were placed in a sample holder, which was mounted on a goniometer. The setup ensured that the rotational axis was parallel to the fibre axis and perpendicular to the X-ray beam. A digital imaging plate system (DIP-3200) was used for data collection, with an X-ray wavelength of 0.71072 Å and a molybdenum (Mo) target material in the X-ray tube. The resulting imaging plate XRD patterns, captured in Weissenberg geometry [8], for all five cotton fibre varieties are shown in Fig. 1. The imaging plate data were further processed using the MOSFLM software package, which was provided with the XRD instrument, to convert the diffraction patterns into line profile analyses by plotting intensity versus 2θ.

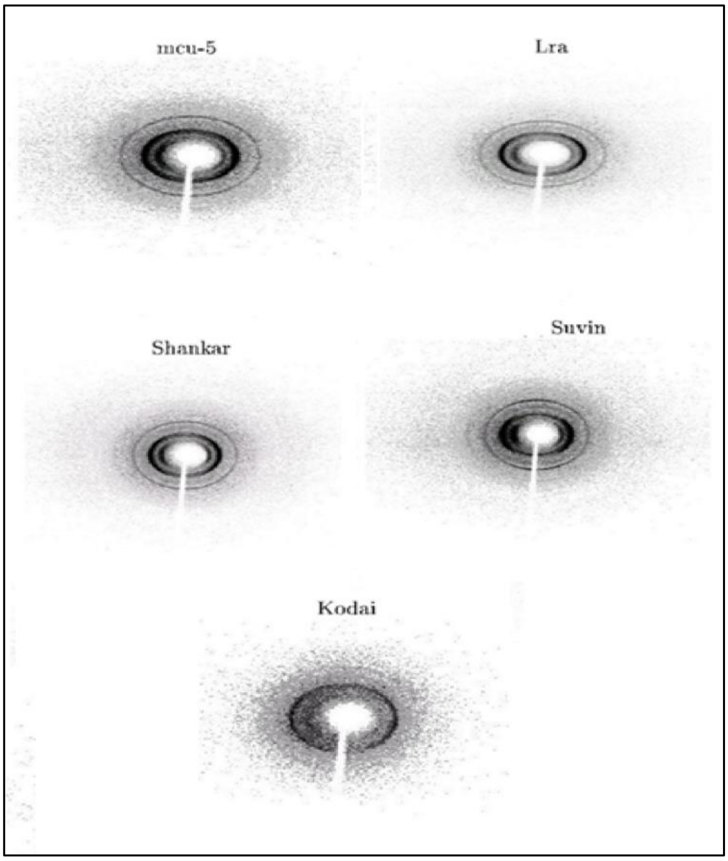


Figure 1: XRD pattern of varieties of cotton fibres

Results and Discussion

1. Crystal Structure using Linked Atom Least Square (LALS) Method

The Linked Atom Least Square (LALS) mathematical program was originally developed in Algol by Alan Wonacott and later translated into Fortran by R. Chandrasekaran, David Dover, David Hukins, and Bill Scott [10]. This software is designed for refining molecular structures of polymer materials and generating structural models using standard bond angles and bond lengths [12, 13]. The LALS software package was compiled on a Linux-based PC for this study.

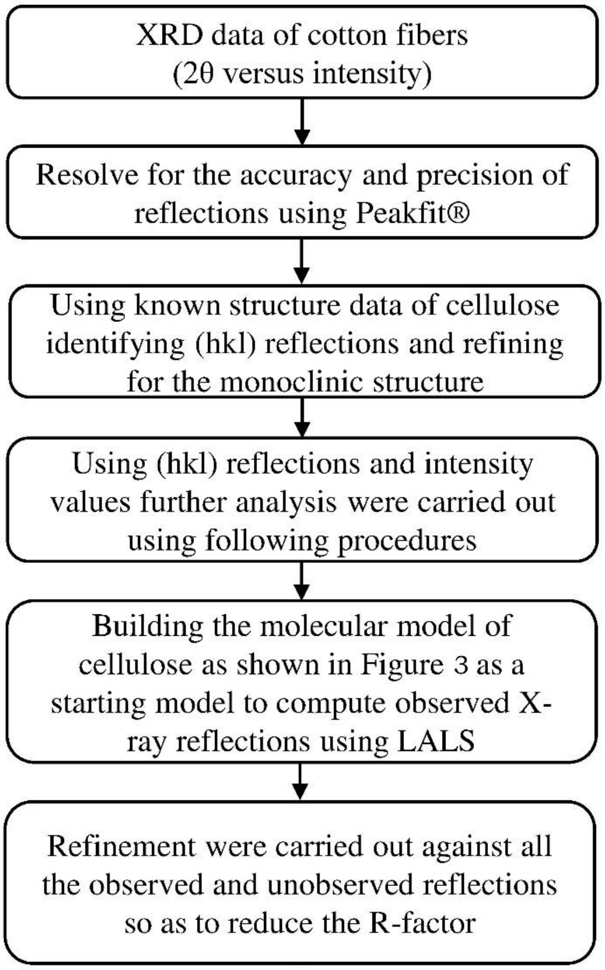


Figure 2: Flowchart to compute molecular and atomic structures of cotton fibres employing LALS method

Cotton cellulose consists of pyranose rings linked by β(1-4) glucosidic bonds, adopting a chair conformation, which is the most stable arrangement in the solid state [13]. Standard bond lengths and bond angles were referenced from our previous study [14]. The polymer chains occupy specific positions within the unit cell, such as (u = 0.25, v = 0.0) and (u = 0.75, v = 0.0), aligning along the crystallographic axes. These positions were used to arrange two polymer chains with a 2/1-helical symmetry in a unit cell within the $P2_1$ space group. Refinement was conducted by searching the azimuthal angles μ_1 and μ_2 within the asymmetric unit and optimizing the positional parameter ω of the polymer chain along the *c*-axis. The refinement process was applied to all diffraction reflections. The methodology for determining atomic and molecular structures using the LALS program is outlined in the flowchart in Fig. 2. The molecular model of the analysed cotton fibres is shown in Fig. 3.

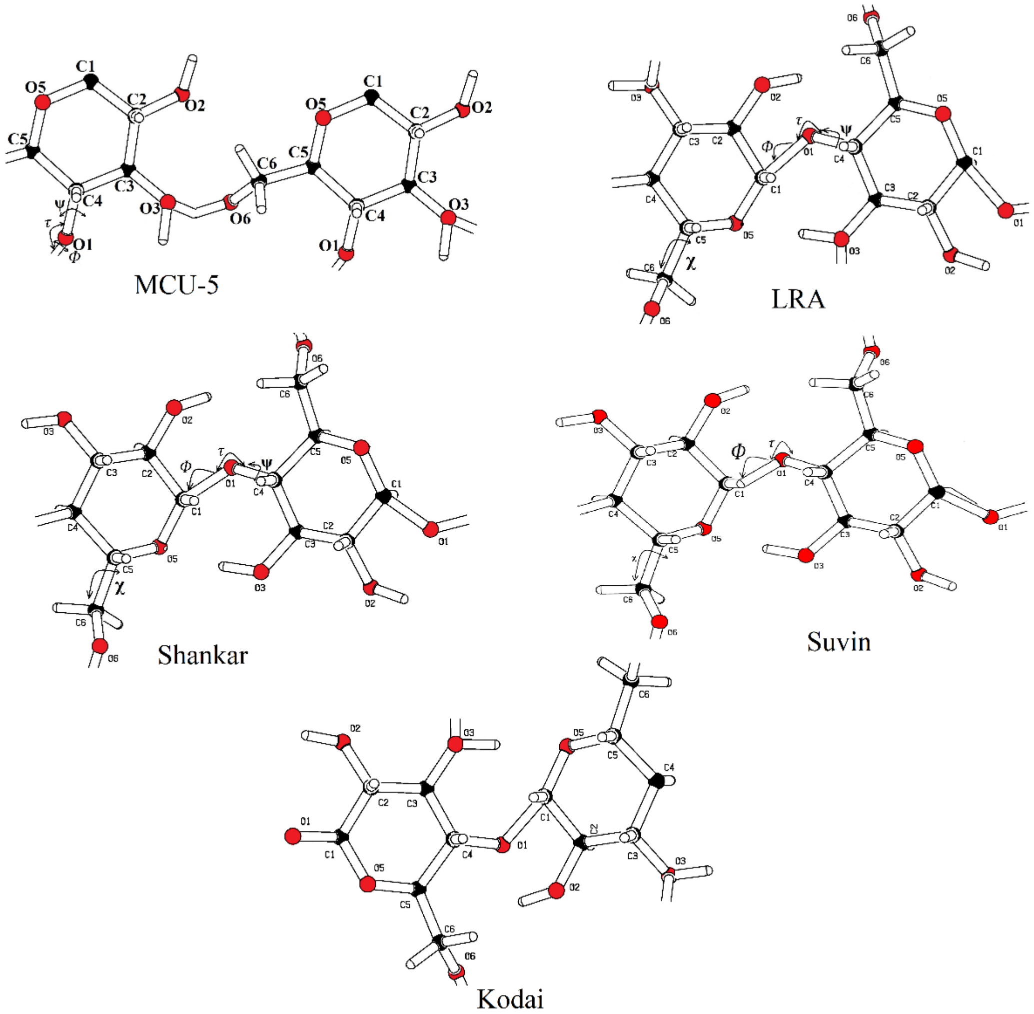


Figure 3: The molecular model of MCU-5, LRA, Shankar, Suvin and Kodai cotton fibres

Fig. 3 presents the molecular structures of five distinct compounds labelled MCU-5, LRA, Shankar, Suvin, and Kodai, each displaying a unique arrangement of atoms. These molecules primarily consist of carbon, hydrogen, and oxygen, with oxygen atoms highlighted in red, which play a crucial role in determining the molecular properties. The variations in connectivity, bond angles, and spatial arrangements suggest structural diversity among these compounds. The presence of oxygen atoms in different positions implies the existence of functional groups such as ethers, carbonyls, or hydroxyls, which can significantly impact the chemical reactivity, solubility, and overall functionality of these molecules. Additionally, the use of wedge and dash notations indicates chiral centres, suggesting stereochemical differences that may influence their physical and biological properties. These molecules could represent different modifications of a core structure, potentially derived from natural polymers, carbohydrates, or cellulose-related compounds. The differences in molecular structures may result from variations in synthesis methods, sources, or crystallographic arrangements. Understanding these structures is essential for exploring their potential applications in materials science, biochemistry, or polymer research. The detailed visualization aids in comparing molecular configurations, helping researchers determine how these structural differences influence the mechanical, thermal, or chemical behaviour of the materials.

Conclusion:

The XRD and LALS analysis of MCU-5, LRA, Shankar, Suvin, and Kodai cotton fibres have provided valuable insights into their structural properties. The LALS program, refined against XRD data, allowed for accurate determination of the crystal structure and molecular arrangement of these cotton fibres. The cellulose chains in these fibres exhibit a consistent chair conformation, with distinct orientations along the crystallographic axes. The use of the $P2_1$ space group revealed the helical symmetry of the polymer chains within the unit cell. These findings enhance our understanding of cotton fibres' structural stability and molecular organization, which is essential for optimizing their use in biodegradable food packaging. The results highlight the importance of molecular alignment and symmetry in determining the mechanical properties of natural fibres. The study offers a framework for further research into the application of cotton fibres in sustainable material development.

References:

1. Wulfhorst, B., & Gries, T. (2012). *Textile technology*. Carl Hanser Verlag GmbH Co KG.
2. Wakelyn, P. J., Bertoniere, N. R., French, A. D., Thibodeaux, D. P., Triplett, B. A., Rousselle, M. A., & Gamble, G. R. (2006). *Cotton fiber chemistry and technology*. CRC Press.
3. Wakelyn, P. J., & Chaudhry, M. R. (2009). Organic cotton: Production practices and post-harvest considerations. In *Sustainable textiles* (pp. 231–301). Woodhead Publishing.

4. Christou, P., & Klee, H. (2004). *Handbook of plant biotechnology* (No. LC-0239). John Wiley and Sons.
5. Samir, O. M., & Somashekar, R. (2007). Crystal structure and elastic constants of Dharwar cotton fibre using WAXS data. *Bulletin of Materials Science, 30*(5), 503–510.
6. Gaillac, R., Pullumbi, P., & Coudert, F. X. (2016). ELATE: An open-source online application for analysis and visualization of elastic tensors. *Journal of Physics: Condensed Matter, 28*(27), 275201.
7. Manju, V. V., Divakara, S., Karthik, D., & Somashekar, R. (2020). Crystallite shape, dielectric constant, and functional data analysis of various cotton fibres using WAXS data. *Indian Journal of Fibre & Textile Research (IJFTR), 45*(1), 49–56.
8. Yakel, H. L., & Fankuchen, I. (1962). Systematic multiple diffraction in equi-inclination Weissenberg geometry. *Acta Crystallographica, 15*(11), 1188.
9. Chen, R., Jakes, K. A., & Foreman, D. W. (2004). Peak-fitting analysis of cotton fiber powder X-ray diffraction spectra. *Journal of Applied Polymer Science, 93*(5), 2019–2024.
10. Manju, V. V., Divakara, S., & Somashekar, R. (2020). Studies on structure and elasto-mechanical properties of Suvin cotton fibre. *Journal of Scientific Research, 12*(4), 607–620.
11. Manju, V. V., Divakara, S., Hegde, V. N., & Somashekar, R. (2020, November). Computation of sample space from XRD data of varieties of cotton fibers. In *AIP Conference Proceedings* (Vol. 2265, No. 1, p. 030344). AIP Publishing LLC.
12. El Bakri, Y., Lai, C. H., Sebhaoui, J., Ali, A. B., Essassi, E. M., & Mague, J. T. (2019). Synthesis, spectroscopic characterization, thermal, XRD crystal structure, the PLATON structural analysis, and theoretical studies of a new 1, 2, 4-triazolo-[1, 5-a] pyrimidines derivatives. *Journal of Molecular Structure, 1184*, 12–24.
13. Samir, O. M., Madhu, S., & Somashekar, R. (2010). X-ray diffraction analysis of Yemeni cotton fibers. *Fibers and Polymers, 11*(3), 413–421.
14. Smith, P. C., & Arnott, S. (1978). LALS: A linked-atom least-squares reciprocal-space refinement system incorporating stereochemical restraints to supplement sparse diffraction data. *Acta Crystallographica Section A: Crystal Physics, Diffraction, Theoretical and General Crystallography, 34*(1), 3–11.

KANJI- A HEALTHY TRADITIONAL INDIAN PROBIOTIC DRINK

Arvinda Shaw

Department of Food and Nutrition,

Raidighi College (affiliated to the University of Calcutta), South 24 Parganas, West Bengal.

Corresponding author E-mail: arvinda@raidighicollege.org.in

Abstract:

Due to lifestyle changes, there is an increased demand for functional foods that would exert nutritional and potential health benefits. Unfortunately, due to a lack of adequate information about our rich diverse Indian food culture, we are unaware that the variety of fruits and vegetables we harvest each season in our country can be utilised as potent functional foods. India has a rich diverse tradition of fermented foods and beverages prepared by local people from regional resources. Fermentation has been a prominent technique in preparing traditional foods and drinks since ancient times. It is a natural process, where sugars are converted into alcohol and carbon dioxide by the action of microorganisms such as yeast or bacteria which increases the nutritional content of food in terms of -amino acids, vitamins, minerals, acids, flavour, and aroma. Regular intake of such food items is known to exert an overall positive impact on human health. Kanji is one such popular traditional North-Indian fermented drink rich in probiotics. Probiotics - "a viable mono or mixed culture of bacteria which, when applied to animal or man, beneficially affects the host by improving the properties of the indigenous flora". Kanji is a pungent-zingy-tasting fermented traditional beverage usually prepared using black carrots, beetroots, spices, salt, and water. The contents are fermented in a jar for 2 to 3 days or till the desired result is achieved. The unique flavour and enhanced nutritional profile are mainly imparted by the microorganism-Lactic Acid Bacilli (LAB) which breaks down the sugars in the carrots. This drink is thus rich in antioxidants such as anthocyanins from black carrots, betalains from beetroot, and dietary fibres along with being a good source of vitamins K, C, B12, potassium and magnesium. Scientific studies indicate beneficial bacteria or probiotics, not only boost gut health but also improve digestion, reduce digestive ailments like nausea, bloating, diarrhoea, and constipation, enhance nutrient absorption and strengthen our immune system. Regular consumption of such fermented beverages during the season is known to improve eyesight, and skin, and help manage blood pressure levels. Kanji is one such drink which is usually taken from winter till Holi but due to its

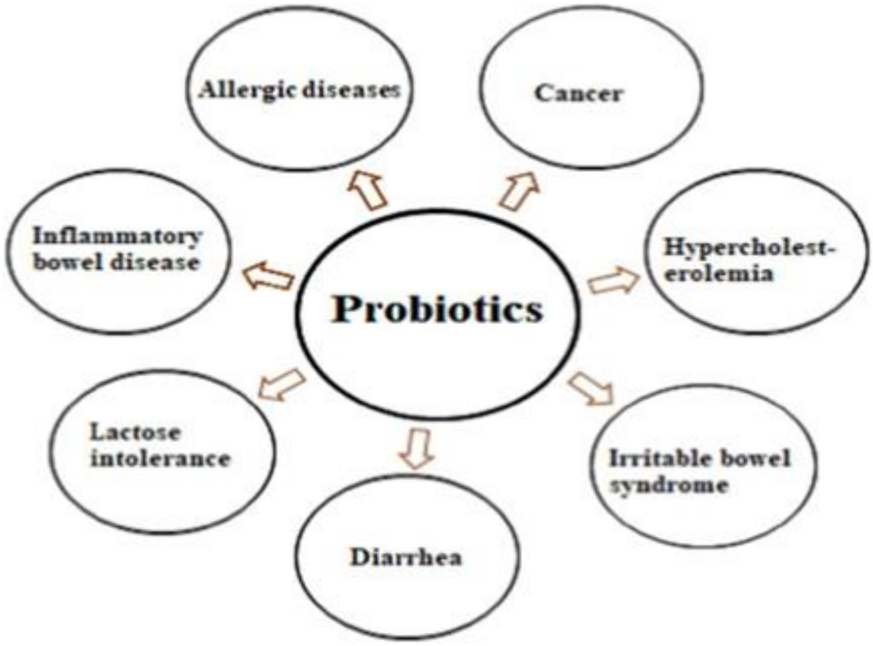
health benefits and soothing effect, it can be consumed during the summer season too depending on the availability of the main ingredients used in it. Traditional homemade Kanji preparation has been found to contain a greater amount of probiotic, antioxidant and antimicrobial content in comparison to processed probiotic drinks. Such easy-to-prepare, pocket-friendly fermented drinks should be part of our daily diets to reap the immense health benefits of probiotics on our overall health.

Keywords: Fermentation, Traditional Beverage, Gut Health, Probiotics.

Introduction:

Post-pandemic people across the globe have become conscious about their attitude towards health, dietary requirements and overall wellness thus leading to increased demand for functional foods having potential health-promoting benefits. Functional foods are foods of the future with ever-evolving new food technologies. The market for Fortified/Functional beverages in India is vastly growing due to lifestyle changes and health consciousness. Thus, India has turned into the 15th largest health and wellness market in the world. (1) Traditional fermented foods are defined as foods produced by native people using their inherited knowledge and skilful technology from local producers and it is known to be one of the oldest biotechnological processes used from ancient times. (2) India has a rich diverse tradition of fermented foods and beverages prepared by local people from regional resources but unfortunately, people are not aware that the ample varieties of fruits and vegetables that are grown in our country in each season can be effectively turned into valuable functional foods. (3) With the application of indigenous knowledge more than 1000 varieties of ethnic fermented foods and alcoholic beverages are produced in India either by natural process or by the addition of mixed starter cultures. (4)

The ancient societies have developed their unique methods of food preservation to preserve and store surplus agricultural produce to be used during harsh seasons, for ritual ceremonies, and to enhance the organoleptic properties of food. Fermentation is one such process which not only extends the shelf life of the food product but also enhances its sensory qualities and nutritional value. (5) Fermented foods are defined as foods or beverages produced through controlled microbial growth and the conversion of food components through enzymatic action. (6) These functional microorganisms such as various strains of lactic acid bacteria (LAB) and yeast play a vital role in bio- preservation of perishable foods, bio-enrichment of nutritional value, protective properties, bioavailability of minerals, production of antioxidants, antimicrobial activities, non-production of biogenic amines, and probiotic properties thus imparting innumerable health-promoting benefits to the consumers. [4] Probiotic food products are in concatenation with such foods and are viable selective microbial dietary supplements which are known to enhance gut flora when provided in an appropriate amount apart from general nutrition. The impact on human health of probiotic lactic acid fermented foods has been promptly suggested by health and medical professionals. [7]



(s)https://www.frontiersin.org/journals/microbiology/articles/10.3389/fmicb.2023.1216674/full [8]

Fermentation is an inexpensive technique widely used in many developing countries to prepare various traditional fermented foods and beverages. [3] Kanji is one such traditionally fermented drink, particularly popular in Northern India, especially in the states of Punjab, Uttar Pradesh, and Rajasthan. This vibrant red-hued probiotic drink is traditionally prepared in households by natural lactic acid fermentation process from grated or diced anthocyanin-rich black carrots (Daucus carota subsp. sativus), mustard seeds and various condiments and spices for a unique tangy taste and flavour. It is consumed during winters till Holi for its probiotic properties excellent for gut health as well as in the summer season to keep the body cool from the effects of extreme heat and promote well-being. This unique beverage, having both prebiotic and probiotic components, has shown a good diuretic effect, soothing effect on the digestive tract, and hepato-protective actions, testifying to its immense beneficial potential. [9]

Background of Kanji:

Kanji dates to the records of the Indus Valley. It is traditionally made from black carrots which are hard to be found these days. However, as history tells it, the carrots which were black and yellow were cultivated the earliest, but the orange-coloured carrots grown in the West gained popularity and replaced all other varieties. Black carrots get their colour from anthocyanin which is a flavonoid high in antioxidants and is known to have ample health benefits. The taste of black carrots is also quite different from the common orange carrots that we usually see in markets. Kanji is largely made during the winter as black carrots are usually available only during that season. However, one can make Kanji all year round by using beetroots and orange carrots instead of black ones. Another reason for drinking Kanji in winter was its role as an immunity booster because the chances of falling ill are greater during that season. The ingredients act as a shield against seasonal diseases, and digestive ailments. The carrots and beetroot sticks add great flavour to salads, sandwiches, wraps and even chapatis and are a great source of prebiotics. (10)

Recipe of the beverage:

The ingredients used in making the fermented Kanji drink requires:

- black carrots
- mustard seeds
- black pepper powder
- red chilli powder
- black salt
- water

In a glass jar or clay pot- properly washed, peeled and thin long pieces of black carrots are placed. To it, coarsely grounded mustard seeds are added along with black pepper powder, red chilli powder, black salt, and adequate water. Everything is stirred well, and the head of the jar is covered with a thin muslin cloth cover. This jar of mixture is then placed in a place that receives sunlight. The mixture is stirred every day with a clean ladle for 3 to 5 days until the desired product is ready to serve. (11) If black carrots are not available then beetroots and orange carrots can be used to reap the benefits of this healthy drink. (check annexure)

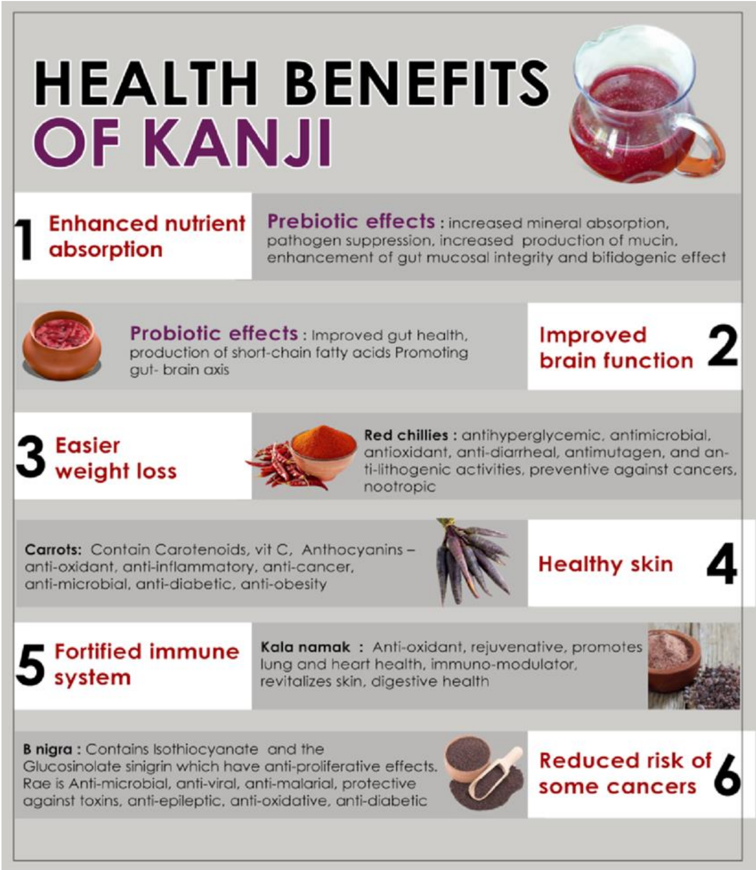
Importance of Kanji as a plant-based fermented drink:

Usually, most of the probiotic foods are primarily made from dairy products but in recent times, people are showing greater interest towards plant-based fermented products for their immense health benefits. Apart from that, there has been an increase in the number of lactose intolerant people in developing countries, their higher cholesterol levels of dairy foods are a cause for concern for weight watchers and related health issues, and economic constraints thus necessitate seeking out other alternatives promising higher nutritional value along with health-promoting factors and from products which have lower cholesterol content yet rich in protein, minerals, fibres, vitamins, and antioxidant contents. Plant-based fermented products are preferred on account of their bioactive properties along with their wholesome nutrient profile and unique taste and flavour. (7)

Health Benefits of Kanji Drink:

Therapeutic Benefits of Kanji: Black Carrots (9):

- Carrots are rich in phytochemicals, phenolic compounds including chlorogenic acid, caffeic acid, quercetin, and ferulic acid, antioxidants, minerals such as calcium, potassium, magnesium, phosphorus, sodium, zinc, iron, and other nutrients.
- Flavonoid content of black carrots is greater when compared to orange carrots. They are also rich in carotenoids, including lutein and beta-carotene.
- Phenolic compounds and antioxidants in carrots promote the multiplication of probiotic microbes beneficial for human health. Nutritional analysis studies have shown that Kanji can be promoted as a promising alternative drink to dairy probiotic products as it effectively provides plant-based novel probiotic strains, namely *Lactobacillus curvatus, Lactobacillus delbrueckii, and Lactobacillus coryniformis.*
- Lactobacillus plantarum isolated from Kanji drink was evaluated as a potential source of Vitamin B12. Black carrots are also a good source of ascorbic acid (vitamin C), a strong antioxidant and vital nutrient involved in various functions such as collagen synthesis, wound healing, and immune system support.
- Being a cheap source of anthocyanins, black carrots have gained popularity in the food industry for various reasons. High content of anthocyanin pigments, a group of phenolic compounds that provide colour are known for their anti-inflammatory, antioxidant, antimicrobial, anti-obesity, anti-diabetic, anti-cancer effects and reduced risk of cardiovascular diseases (CVDs).



(s) Bali S, Kumar V, Goutam A (2024) Kanji Drink: The Tangy Carrot Beverage for Good Health. Curr Res Cmpl Alt Med 8: 229.

***Probiotic effects of Kanji* (9)(12):**

- During the fermentation process of this unique beverage, microflora mainly Lactic Acid Bacilli (LAB), play a crucial role in breaking down the sugars in the carrots and producing lactic acid. Fermentation not only imparts a unique flavour but also plays an important role in the function and integrity of the gastrointestinal tract, maintenance of immune homeostasis and host energy metabolism. Alterations in the composition of the intestinal microbiome have been associated with infections in the gastrointestinal tract, and inflammatory bowel disease (IBD). Probiotics produce anti-microbial agents or metabolic compounds that suppress the growth of other microorganisms or compete for receptors and binding sites with other intestinal microbes on the intestinal mucosa.
- The antimicrobial effect of bacteriocin derived from the Lactobacillus growing on fermented carrot kanji shows potent bactericidal activity against Staphylococcus aureus, which is a major cause of food poisoning through toxin-mediated virulence.

This inhibitory activity suggests the potential application of black carrot kanji as a probiotic.

- Scientific studies compared the therapeutic potency of homemade Kanji with Market-Ready Probiotic Drinks and found that traditional homemade Kanji drinks possess a greater concentration of probiotic, antioxidant, and antimicrobial profiles than bottled probiotic drinks.

Therapeutic effects of Kanji: mustard seeds: [9]

- Brassica nigra or mustard seeds, contain a variety of phytochemicals, including alkaloids, saponins, tannins, and a range of polyphenols such as flavonoids (flavonols,
  flavones, flavan-3-ols, anthocyanidins, flavanones, and isoflavones) and non-flavonoids (phenolic acids, hydroxycinnamates, stilbenes etc.
- The major fatty acids present in these seed oils are palmitic, stearic, oleic, linoleic, linolenic, eicosanoic, and erucic acids.
- Significant anticancer properties, especially against human non-small cell lung cancer cell lines have been demonstrated through scientific studies done on Brassica nigra seed extracts. It has been found to suppress the migratory and invasive activity of the cancer cells, by modulating the expression of key proteins involved in these processes.
- In liver tissue, the presence of isothiocyanate in the seed extract plays a key role in anti-proliferative effects, suggesting protective benefits against the development or progression of liver cancer.
- The aqueous extract of Brassica nigra seeds demonstrates notable antimicrobial activity by effectively inhibiting several harmful bacteria, including Escherichia coli, Klebsiella pneumonia, Salmonella para-typhi, Pseudomonas aeruginosa, and Staphylococcus aureus.
- Significant antimalarial properties have been demonstrated by B.nigra seed extracts against Plasmodium berghei infection in mice. The active compounds present in the seeds could be effective for malaria treatment and prevention mainly in areas like north-west India, where mosquito breeding starts with the onset of Holi (in March) and proliferate all through the summers. Coincidentally, the dark, maroon-coloured Kanji drink is prepared in north India at the time of Holi since the drink is traditionally associated with this festival of colours.

- Antiviral properties against SARS-CoV-2 were studied and it was found that the methanolic extract of Brassica nigra seeds inhibited the SARS-CoV-2 chymotrypsin-like protease (3CLPro), crucial for the virus's replication.
- Protective effects are exhibited by these seeds against oxidative stress and tissue damage caused by toxic substances.
- The anticonvulsant effects of Brassica nigra seed extract were observed in a study using the kindling method in mice which demonstrated a significant reduction in the intensity, frequency, and duration of seizures.

***Therapeutic effects of Kanji: red chilli**: [9]*

- Phytochemicals found in chilli pepper are found to decrease the risk of several chronic diseases.
- Phenolic compounds of red chilli like flavonoids, β-catenin, capsaicinoids, glycolipids, and carotenoids showed - anti-atherogenic, antihyperglycemic, antimicrobial, antioxidant, anti-diarrheal, antimutagen, and anti-lithogenic activities.
- The high free radical scavenging properties are exhibited by carotenoid pigments like capsanthin, cryptocapsin, and capsorubin.
- Activation of the apoptosis pathway in human KB (human epithelial carcinoma) cancer cells and mitochondrial-mediated caspase activation. The protective effect of capsaicin helps to reduce the risk of cancers through the inhibition of the NF-κB pathway. Capsaicin is a strong prophylactic agent in the prevention of skin and lung cancers.
- The antimicrobial properties of chilli pepper can alter the gut microbiota, improving the microbiome.
- Capsaicin has been proven to protect against heart disease through the regulation of coronary blood flow, and prevention of heart arrhythmias. It also gives relief from stiff joints, rheumatism, bronchitis, chest colds, and arthritis.
- Capsaicin can promote the depletion of substance P in the nerve endings, thus reducing pain and tenderness.
- Bioactive compounds found in red chillies have been found to have several beneficial effects on brain functioning for example lutein and β-carotene have been found to promote a positive effect on memory.
- Red chilli extracts have also been found to be effective in suppressing major

enzymes associated with Alzheimer's disease.

Therapeutic benefits of Kanji: Black salt: [13][14]

Black salt is another ingredient used in preparing Kanji, it is a form of rock salt. Ayurveda considers black salt to be a cooling condiment that may impart many health benefits such as follows:

- Contains modest amounts of iron which may help to deal with iron deficiency anaemia.
- It may help with digestive health by promoting digestion, relieving bloating and acid reflux, increasing the natural production of acid in the stomach, and increasing the formation of bile juice in the liver. It may also help with the absorption of nutrients from the small intestine.
- It has laxative properties so it can be beneficial in the relief of constipation More scientific studies are required.
- Eliminates excess phlegm in babies.
- Anti-inflammatory effects may aid in the natural healing of skin.
- It helps improve hair texture, reduce dandruff, repair split ends and controlling excessive hair fall.
- Black salt is widely used in anti-obesity and anti-cholesterol products due to its dissolving and disintegrating effect.
- Eases muscle spasms.

Conclusion:

Kanji is a traditional probiotic drink with immense health attributes. This non-dairy-based fermented drink contains phytochemicals, carotenoids, anthocyanins, polyacetylenes and phenolics making Kanji an assemblage for good health. Black carrots contain several useful bioactive compounds, but they are grown in specific regions and seasons, so beetroot and carrot kanji variants can also be prepared to reap their health benefits. In Indian culture, such fermented drinks have been and are still being used as home remedies for various gastrointestinal disturbances like anorexia, bloating, indigestion, and diarrhoea. This low-cost, lactose-free, easy-to-make fermented drink is very popular in the northern parts of India but it is recommended to be incorporated into the daily diets of others for its huge gut health-boosting properties.

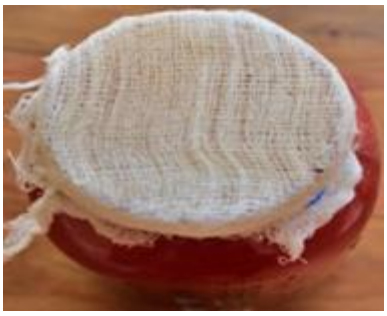
Annexure: Steps to Prepare -Kanji Drink at Home:

Ingredients

Wash, clean and cut carrots into thin long pieces

Crush the mustard seeds

Put all the ingredients in jar filled with water and stir well



Cover the mouth of the jar with a thin cloth and place the jar in a place with sunshine for 4 days

Servings: 12; Preparation time: 10 minutes; Calories: 30 kcal; Fermenting time: 4 days [11]

- 2 beets
- 1 large purple carrot (when unavailable the red variant can also be used)
- 2 tablespoons ground mustard seeds
- 1 tablespoon roasted cumin seeds
- 1 tablespoon black salt (or Himalayan pink salt) – adjust to taste.
- 1 teaspoon red chilli powder (or to taste)
- 6 cups of Luke-warm water.

References:

1. Functional foods and beverages in India. https://agriculture.canada.ca/en/international-trade/market-intelligence/reports/sector-trend-analysis-functional-foods-and beverages-India
2. Traditional Fermented Products of India. Rawat K. et.al. Int. J. Curr. Microbial. App. Sci (2018);7 (4): 1873-1883.

3. Lamba J., Goomer S., Saxena S.K. Study the Lactic Acid bacteria content in traditional fermented Indian drink: Kanji. International Journal of Gastronomy and Food Science. Vol 16, July 2019, 100143.
4. Tamang J.P., Thapa N., Bhalla T.C., Savitri. Ethnic Fermented Foods and Beverages of India. In book: Ethnic Fermented Foods and Alcoholic Beverages of Asia (pp.17-72).Springer India; August 2016.
5. Mannaa M. *et al.* Evolution of Food Fermentation Processes and the Use of Multi-Omnics in Deciphering the Roles of the Microbiota. Foods. 2021 Nov; 10(11):2861.
6. Dimidi E. et. al. Fermented Foods: Definitions and Characteristics, Impact on the Gut Microbiota and Effects on Gastrointestinal Health and Disease. Nutrients. 2019 Aug; 11(8):1806.
7. Sharma C., et. al. Physicochemical and microbiological evaluation of antioxidant-rich traditional black carrot beverage: Kanji. Bull Natl Res Cent. 2021; 45(1):143.
8. Latif. A. et.al. Probiotics: mechanism of action, health benefits and their application in foodindustries.Font.Microbiol.https://www.frontiersin.org/journals/microbiology/articles/10.3389/fmicb.2023.1216674/full (updated 17th Aug 2023)
9. Bali S., Kumar V., Goutam A. (2024) Kanji Drink: The Tangy Carrot Beverage for Good Health. Curr Res Cmpl Alt Med 8: 229. DOI: 10.29011/2577-2201.100229
10. Salwan T. Kanji: A Miracle Drink with Ample Health Benefits. Updated: Aug 02, 2022.https://www.slurrp.com/article/kanji-a-miracle-drink-with-ample-health=benefits-1659431738069
11. https://www.aromaandessence.com/beet-probiotic-drink/
12. Hemarajata. P. and Versalovic. J. Effects of probiotics on gut microbiota: mechanism of intestinal immunomodulation and neuromodulation. Therap Adv Gastroenterol.2013 Jan; 6(1):39-51.
13. Basu. D. *et al.,* Discard Biochemical Malfunction by Black Salt Through Naturopathy. European Journal of Pharmaceutical and Medical Research. 2015, 2(6), 96-101.
14. Pal. A. Black Salt: Uses, Benefits, Side Effects, Precautions and more! https://pharmeasy.in/blog/ayurveda-uses-benefits-side-effects-precautions-of-black-salt/ (updated on March 5, 2024)

NOVEL TRENDS IN FOOD PACKAGING

Roonal Kataria[1] and Arjumanara Surti[2]

[1]Department of Microbiology,

Jai Hind College, (Empowered Autonomous), Mumbai

[2]Department of Microbiology,

Sophia College for Women, (Empowered Autonomous), Mumbai

Corresponding author E-mail: roonal.kataria@jaihindcollege.edu.in,

arjumansurti@gmail.com

Abstract:

Recent trends in food packaging focus on sustainability, active and intelligent technologies, and edible solutions. Active packaging interacts with food to maintain quality and safety, while intelligent packaging monitors food properties. Edible packaging, made from biodegradable materials, serves as a consumable wrapping or coating, generating no waste. Nanotechnology enhances edible packaging functionality by incorporating bioactives, antimicrobials, and nutrients. Sustainable packaging includes bioplastics derived from polysaccharides, proteins, and lipids. Innovative packaging technologies aim to extend shelf life, prevent microbial growth, and improve barrier properties. These advancements address consumer demands for fresh, safe, and nutritious food while minimizing environmental impact. Although widely accepted in some countries, these technologies are still emerging in developing countries. This review explores some of the most noteworthy trends in food packaging, highlighting their impact on the industry and their potential for future development.

Keywords: Sustainable Packaging, Active Packaging, Edible Packaging

Introduction:

Food packaging technology is a vast and evolving field that plays a crucial role in preserving food quality, extending shelf life, and ensuring food safety. In recent years, food packaging has undergone significant transformations, driven by both consumer demand and the growing concerns over environmental sustainability, waste management, and the negative effects of traditional petroleum-based plastics. Innovation in food packaging has moved far beyond traditional materials like glass, plastic, and metal to incorporate a range of new technologies and designs that promise to revolutionize the way we store, preserve, and consume food. This chapter explores some of the most noteworthy trends in food packaging, highlighting their impact on the industry and their potential for future development.

1. Sustainable and Eco-Friendly Materials

Traditional food packaging materials, primarily made from plastic, aluminum, glass, and paper, have raised significant environmental concerns. Plastics, particularly single-use packaging, are not biodegradable and often contribute to landfills, marine pollution, and greenhouse gas emissions. The global consumption of plastic packaging continues to rise, with an estimated 300 million tons of plastic waste produced annually (Jambeck *et al.,* 2015). The vast accumulation of plastic waste has motivated the shift toward alternatives that are renewable, biodegradable, and environmentally friendly. As environmental consciousness grows, consumers and companies alike are seeking packaging solutions that minimize waste and environmental impact (Pereira *et al.,* 2019, Niaz *et al.,* 2020). The rise in eco-friendly food packaging reflects a global shift towards sustainability, with companies aiming to reduce their carbon footprints, cut down on plastic waste, and use materials that are recyclable, biodegradable, or compostable (Gallo *et al.,* 2020, Gupta *et al.,* 2020).

Plant-Based Plastics:

Biodegradable plastics, derived from renewable resources such as starch, polylactic acid (PLA), polyhydroxyalkanoates (PHA), and cellulose, offer a promising alternative to petroleum-based plastics. PLA, produced from fermented plant starch (usually corn), has gained popularity due to its relatively low environmental impact, compostability, and ability to decompose into natural substances (Kumar *et al.,* 2021). PHA, produced by bacteria from renewable resources, has also shown promise as an eco-friendly food packaging material, as it is both biodegradable and non-toxic (Laycock *et al.,* 2017).

While biodegradable plastics are an improvement over conventional plastics, their use still faces challenges such as higher production costs, limited durability, and the need for proper disposal infrastructure (Sánchez-García *et al.,* 2011). Plant-based materials such as edible films, coatings, and fibers are emerging as viable alternatives to conventional packaging materials. For instance, edible films made from substances like chitosan (derived from chitin) and alginate (from seaweed) are used to create biodegradable packaging that can either be eaten or composted after use (Nidal *et al.,* 2020). These materials not only offer biodegradability but also have the potential to enhance food preservation by acting as natural barriers to moisture, oxygen, and contaminants.

Further, plant-based fibers like hemp, jute, and bamboo are increasingly being used for producing sustainable packaging. These materials are renewable, biodegradable, and possess excellent mechanical properties for packaging applications (Lee *et al.,* 2020). Their application, however, is still relatively limited compared to conventional packaging materials.

Mushroom mycelium, the root structure of fungi, is gaining attention as a sustainable packaging material due to its biodegradability, lightweight nature, and renewable properties. Mycelium-based packaging has been utilized in creating molded packaging products for food, providing a viable alternative to polystyrene and other plastic-based materials. Notably, companies like Ecovative have successfully commercialized mycelium-based packaging, offering an eco-friendly solution that decomposes within weeks (Van Der Kooij *et al.,* 2021).

Edible Packaging:

One of the most innovative developments in sustainable packaging is edible packaging. Materials like seaweed, rice, and even milk proteins are being used to create wrappers or coatings that can be consumed along with the food they protect. This trend not only eliminates waste but also provides opportunities for novel food experiences. Edible packaging is an innovative approach that combines the convenience of packaging with the added benefit of consumability. Edible films and coatings made from ingredients like starch, protein, or lipids can protect food items from contamination and spoilage while being safe to consume. Additionally, edible packaging can reduce food waste by allowing the packaging to be eaten along with the product (Kaushik *et al.,* 2020)

Several studies have demonstrated that edible packaging can be tailored to suit various food types, offering an innovative and eco-friendly solution that reduces waste and environmental impact (Rhim *et al.,* 2013). However, its widespread adoption faces challenges, such as the development of robust and cost-effective production methods and ensuring the safety and hygiene of edible packaging materials.

2. Smart and Interactive Packaging

Smart and interactive packaging refers to packaging systems that incorporate advanced technologies such as sensors, RFID (Radio Frequency Identification), NFC (Near Field Communication), QR codes, and printed electronics, allowing for better tracking, monitoring, and engagement. These technologies enable the packaging to provide real-time information to consumers, improve product safety, track inventory, and offer enhanced user experiences (Meyer *et al*., 2020, Liu *et al.,* 2021). With the growing demand for personalized, safe, and sustainable packaging, smart and interactive packaging has emerged as a key innovation in the food, beverage, pharmaceutical, and consumer goods industries (Ghaani *et al.,* 2021).

Smart packaging can be categorized into two main types: active packaging and intelligent packaging.

Active Packaging is an innovative approach that goes beyond merely containing food. It interacts with the contents inside the package to extend shelf life, improve safety, or preserve product quality. This type of packaging is especially valuable in extending the freshness of perishable items like fruits, vegetables, and meats (Choi *et al.,* 2019, Alavi *et al.,* 2020).

Oxygen scavengers can work through chemical or enzymatic reactions, where a substance such as iron, ascorbic acid, or natural plant extracts reacts with oxygen molecules inside the package (Gane *et al.,* 2004). Oxygen scavengers are used in the packaging of products like fresh meat, poultry, and bakery items to prevent rancidity, discoloration, and microbial growth (Baldwin *et al.,* 2020). Moisture can lead to the growth of mold or bacteria, so packaging materials that regulate moisture levels are an important tool in reducing food spoilage. Moisture control is a critical factor in maintaining the texture, flavor, and shelf life of many food products (Nicolai *et al.,* 2019, Sanchez *et al.,* 2018). Silica gel, clay, and molecular sieves are commonly used desiccants that absorb moisture in the packaging environment. Humidity regulators, such as zeolites or calcium oxide, can be incorporated into packaging to either absorb or release moisture depending on the product's needs (Deshpande *et al.,* 2019). Coatings that release antimicrobial agents are being developed to slow down the growth of harmful bacteria, mold, or fungi on food surfaces. Common antimicrobial agents include organic acids, essential oils (such as oregano or thyme oil), silver nanoparticles, and chitosan (a biopolymer derived from crustaceans). These agents either leach out of the packaging into the product or actively inhibit microbial growth at the packaging surface (Rhim *et al.,* 2013, Kerry *et al.,* 2015).

Intelligent Packaging includes technologies that provide information about the condition of the product, its origin, or its safety status. It often incorporates sensors or devices that track temperature, humidity, or other environmental variables. It can also include interactive features that engage consumers, such as QR codes, RFID, and NFC (Zhao *et al.,* 2018).

RFID and NFC are widely used in food and pharmaceutical packaging to verify product authenticity, prevent counterfeiting, and improve supply chain management (Meyer *et al.,* 2020, Kher *et al.,* 2020). Quick Response (QR) codes are widely used in interactive packaging to engage consumers and provide instant access to product-related information through smartphones. By scanning the code, consumers can access nutrition facts, product origin, recipes, and special promotions (Choi *et al.,* 2021). Augmented Reality (AR) has further enhanced the interactive experience by overlaying digital content (e.g., 3D models, animations, or videos) on the real-world packaging via a smartphone or AR glasses. This technology allows brands to create interactive and engaging experiences that can be tailored to individual consumers, improving product visibility and fostering consumer loyalty (Pereira *et al.,* 2022).

Sensors integrated into packaging can measure various parameters such as temperature, humidity, pH levels, or gas composition to monitor the condition of the product throughout its lifecycle. These sensors can be placed directly on the packaging surface or embedded within it to detect spoilage or potential contamination (Pantelidou *et al.,* 2021). Printed electronics, including sensors and displays, are gaining traction due to their flexibility, low cost, and ease of integration into packaging. These printed systems can be used to monitor and report on the freshness of the product, alerting consumers to potential quality issues (Fierens *et al.,* 2017). Similarly, fresh food products can use sensors to signal when they are nearing spoilage, ensuring consumers consume them before quality degrades (Sanz *et al.,* 2020).

3. Personalized Packaging

Personalized packaging refers to packaging systems that are customized to meet the specific needs or preferences of individual consumers. Unlike traditional packaging that caters to the mass market, personalized packaging allows brands to engage consumers on a deeper level by incorporating customization, interactivity, and tailored messaging. This can range from adding the consumer's name to a product to creating a completely unique packaging experience based on consumer data or behaviors. The rise of digital technologies, data analytics, and consumer-centric marketing strategies has paved the way for innovations in personalized packaging, which has found applications across various industries such as food and beverages, cosmetics, pharmaceuticals, and consumer electronics.

Personalized packaging is seen as a tool for enhancing brand identity, fostering customer loyalty, increasing engagement, and differentiating products in an increasingly crowded marketplace. The future of personalized packaging is likely to include integration with the Internet of Things (IoT). This would allow packaging to become even more interactive and responsive, providing real-time data on product usage and allowing for dynamic customization based on consumer behavior (Stojanovic *et al.,* 2021). As sustainability becomes a key concern for both consumers and brands, there is growing interest in creating personalized packaging that is also environmentally friendly. This includes using recyclable materials, minimizing packaging waste, and adopting sustainable printing and production methods (Coles *et al.,* 2020). With the ongoing development of AI, packaging could become more responsive to consumer behaviors in real-time. AI algorithms could predict consumer preferences and adjust packaging elements dynamically, providing a truly personalized experience based on past behaviors, locations, and even emotional responses (Jannasch *et al.,* 2019, Zhang *et al.,* 2020).

Challenges in Food Packaging:

Sustainable packaging options, like biodegradable plastics or plant-based materials, can often be more expensive than traditional plastic. The challenge for manufacturers is finding ways to balance sustainability with cost-effectiveness, especially in the competitive food industry. While sustainability is a major trend, not all consumers are willing to pay a premium for eco-friendly packaging, particularly in price-sensitive markets. Educating consumers on the benefits of sustainable packaging and ensuring it meets their functional needs (e.g., durability and convenience) remains a challenge. As the demand for innovative packaging materials grows, so do the regulatory hurdles. Food packaging must meet food safety standards, and new materials or technologies (e.g., edible packaging or active packaging) may face lengthy approval processes. Ensuring compliance with both national and international regulations is an ongoing challenge. While new materials like bioplastics and edible wraps offer promising benefits, they often don't match the performance of conventional packaging in terms of preserving freshness or preventing contamination. This can be a significant barrier to large-scale adoption in industries where food safety and long shelf life are critical (Siracusa, 2017, Sorrentino *et al.,* 2020).

Even though many food packaging materials are now designed to be recyclable or biodegradable, the infrastructure to properly process these materials is often lacking, particularly in developing regions. This leads to challenges in managing packaging waste effectively and reducing the environmental impact. These trends and challenges show the dynamic nature of food packaging. Companies are striving to strike a balance between sustainability, innovation, and cost-efficiency while meeting consumer expectations and navigating complex regulations (Pereira *et al.,* 2019).

Conclusion:

Food packaging is evolving rapidly as companies strive to meet the growing demand for sustainability, innovation, and functionality. Whether it's through the development of new materials, the integration of smart technologies, or the pursuit of minimalist design, the future of food packaging promises to be exciting and transformative. With the continued push for eco-conscious solutions and the rise of personalized and interactive experiences, packaging will no longer just serve as a protective barrier; it will become a key element in the way consumers interact with food and the way food brands build connections with their audiences.

As these trends continue to emerge and mature, the food packaging industry will undoubtedly play a crucial role in shaping the way we produce, consume, and think about food in the years to come. As technologies continue to advance and sustainability becomes more prominent, personalized packaging will likely play an even larger role in shaping the future of packaging and consumer experiences.

References:

1. Alavi, S. H., *et al.* (2020). Active packaging technologies: A review. Food Packaging and Shelf Life, 25, 100549.
2. Baldwin, E. A., *et al.* (2020). Active packaging systems: Innovations and opportunities for the food industry. Trends in Food Science & Technology, 105, 58-68.
3. Choi, S.., *et al.* (2019). Applications of active packaging in food systems. Comprehensive Reviews in Food Science and Food Safety, 18(4), 1001-1017.
4. Choi, S., *et al.* (2021). The evolution of interactive packaging: Consumer engagement and beyond. Packaging Technology and Science, 34(3), 121-130.
5. Coles, R., *et al.* (2020). Digital printing for personalized packaging: Trends and challenges. Packaging Technology and Science, 33(1), 5-15.
6. Deshpande, S., *et al.* (2019). Active packaging materials for food preservation: A review. Food Research International, 116, 325-338.
7. Fierens, S., *et al.* (2017). Printed electronics for smart packaging applications. Sensors, 17(6), 1234.

8. Gallo, M., *et al.* (2020). Sustainability of food packaging: Consumer preferences and market trends. Packaging Technology and Science, 33(6), 207-218.
9. Gane, P. A. C., *et al.* (2004). Active and intelligent packaging systems. Packaging Technology and Science, 17(4), 179-188.
10. Ghaani, M., *et al.* (2021). Smart and active packaging systems for food applications. Food Control, 121, 107620.
11. Gupta, N., *et al.* (2020). Sustainability challenges in food packaging: Materials, technologies, and opportunities. Sustainability, 12(9), 2904.
12. Jambeck, J. R., *et al.* (2015). Plastic waste inputs from land into the ocean. Science, 347(6223), 768-771.
13. Jannasch, P., *et al.* (2019). QR codes and NFC: Enabling personalized packaging. Food Control, 101, 73-82.
14. Kaushik, N., *et al.* (2020). Innovative approaches in sustainable packaging for food preservation. Trends in Food Science & Technology, 103, 244-255.
15. Kerry, J. P., *et al.* (2006). Packaging technologies for active and intelligent packaging. Food Research International, 39(6), 601-609.
16. Kher, S., *et al.* (2020). Smart packaging for the food industry: A review. Trends in Food Science & Technology, 102, 228-239.
17. Kumar, A., *et al.* (2021). Polylactic acid-based biodegradable plastics for sustainable food packaging: A review. Food Packaging and Shelf Life, 27, 100644.
18. Laycock, B., *et al.* (2017). Polyhydroxyalkanoates: Biodegradable plastics from renewable resources. Nature Reviews Microbiology, 15, 153-170.
19. Lee, W. J., *et al.* (2020). Development of biodegradable packaging materials from natural fibers. Industrial Crops and Products, 150, 112423.
20. Liu, X., *et al.* (2021). Recent advances in active and intelligent food packaging materials. Trends in Food Science & Technology, 106, 144-153.
21. Meyer, L., *et al.* (2020). Smart packaging for food safety and traceability: Opportunities and challenges. Food Control, 109, 106914.
22. Niaz, K., *et al.* (2020). Food packaging: Materials, technologies and applications. Food Research International, 127, 108665.
23. Nicolai, B. M., *et al.* (2019). Packaging solutions for fresh food preservation: A review. Food Packaging and Shelf Life, 22, 100416.

24. Nidal, N., *et al.* (2020). Biodegradable edible coatings for food packaging: A review. Food Hydrocolloids, 102, 105639.
25. Pantelidou, A., *et al.* (2021). Sensors in food packaging: A review on the latest developments and challenges. Food Control, 122, 107754.
26. Pereira, R., *et al.* (2019). Sustainable food packaging materials: Challenges and future directions. Current Opinion in Food Science, 27, 1-8.
27. Pereira, R., *et al.* (2022). Augmented reality in packaging: A review of current trends and potential applications. Food Packaging and Shelf Life, 27, 100641.
28. Rhim, J. W., *et al.* (2013). Antimicrobial packaging for food preservation. Food Control, 34(1), 68-74.
29. Rhim, J. W., *et al.* (2013). Edible films and coatings for food packaging: A review. Food Research International, 50(1), 108-116.
30. Sanchez, M. E., *et al.* (2018). Active food packaging materials to extend shelf life and preserve flavor and aroma. Journal of Agricultural and Food Chemistry, 66(2), 368-381.
31. Sánchez-García, M. D., *et al.* (2011). Development of biodegradable materials for food packaging applications. Comprehensive Reviews in Food Science and Food Safety, 10(1), 1-15.
32. Sanz, A., *et al.* (2020). Smart packaging solutions for the pharmaceutical industry. Journal of Pharmaceutical Sciences, 109(4), 1359-1370.
33. Siracusa, V. (2017). Food packaging materials: A review. Food Research International, 95, 86-96.
34. Sorrentino, A., *et al.* (2020). Sustainable active packaging for food: A review. Innovative Food Science & Emerging Technologies, 63, 102363.
35. Stojanovic, J., *et al.* (2021). Augmented reality and personalized packaging: Opportunities and challenges. Journal of Packaging Technology and Research, 5(1), 13-26.
36. Van Der Kooij, A., *et al.* (2021). Mycelium-based packaging materials: A sustainable alternative to plastic. Journal of Cleaner Production, 280, 124260.
37. Zhang, X., *et al.* (2020). Artificial intelligence and data analytics in personalized packaging. Food Packaging and Shelf Life, 24, 100485.
38. Zhao, Z., *et al.* (2018). Technological advances in smart and active food packaging. Journal of Food Science, 83(5), 1115-1127.

THAWING TECHNIQUES AND QUALITY PRESERVATION IN FROZEN FISH: A COMPREHENSIVE REVIEW

Mohit Bamaniya*[1], D. V. Bhola[1], B. G. Chudasama[1],
J. B. Solanki[1], Neha Kharadi[1] and Mayur Bhadarka[2]
[1]Department of Fish Processing Technology,
[2]Department of Aquatic Environmental Management,
College Of Fisheries Science, Kamdhenu University, Veraval 362265
*Corresponding author E-mail: mohitbamaniya7373@gmail.com

Abstract:

Thawing plays a critical role in restoring frozen food, particularly fish, to its original state by reversing the effects of freezing. This process is vital for maintaining the quality, safety, and shelf life of frozen fish, which are highly perishable due to enzymatic and bacterial activity. Various thawing methods exist, including thermal techniques like microwave and air blast thawing, as well as non-thermal methods such as high-pressure, vacuum, and ultrasound thawing. Each method has its advantages and challenges related to thawing speed, energy consumption, and food quality preservation. While thermal methods are faster, they may lead to uneven heating, dehydration, or damage to the fish's appearance and texture. Non-thermal methods, though better at preserving quality, can be more complex and less efficient in terms of heat penetration. Factors such as thawing time, rate, and method significantly influence the moisture content, drip loss, texture, and sensory properties of thawed fish. For instance, rapid thawing methods like water submersion generally reduce drip loss and maintain better quality, while slower methods like microwave thawing lead to greater moisture loss. This review emphasizes the importance of selecting an appropriate thawing technique to minimize quality deterioration and optimize food safety.

Introduction:

Thawing is a crucial process that reverses the effects of freezing by applying heat energy to convert ice back into water, restoring the frozen product to its original state (Balachandran, 2001). This process plays a vital role in food preservation and preparation, ensuring the quality and safety of frozen items like fish. Fish is highly perishable due to enzymatic and bacterial activity. Extending its shelf life is essential to maintain its safety for consumption and high-quality standards. Preservation methods such as cooling and freezing are widely used to slow spoilage without significantly altering the physical properties of the fish (Backi, 2018).

However, thawing can lead to significant physical and chemical changes that affect the quality of frozen foods. Various thawing methods are available, including thermal and non-thermal techniques. Thermal methods, such as microwave, dielectric, or resistive thawing, are fast and convenient but pose challenges like uneven heating, surface overheating, and high energy consumption. Non-thermal methods, like ultra-high pressure, ultrasound, and vacuum thawing, better preserve food quality but face limitations such as poor heat penetration, localized heating, and operational complexity. Improper thawing not only accelerates physical and chemical changes but also encourages microbial growth, ultimately reducing the quality of frozen food products (Cai *et al.,* 2019).

Therefore, selecting the appropriate thawing method is vital to maintaining the integrity and safety of frozen foods. Thawing methods can generally be classified into two primary categories. The first category involves systems that utilize the conduction of heat to transfer thermal energy from the surface to the core of the product. The second category comprises methods that rely on non-conductive techniques, using alternative approaches to achieve uniform thawing. These classifications highlight the diversity of strategies employed to effectively thaw frozen products while preserving their quality and safety (Balachandran, 2001).

Thawing Methods:

1. Thawing in Air:

Thawing frozen fish in water is much faster than air-based methods due to water's superior heat transfer properties. This involves immersing the fish in water tanks or spraying water over it. The water temperature must be carefully regulated to prevent damage, and measures should be taken to avoid the fish absorbing excessive water. While effective, this method can sometimes negatively affect the fish's flavor, taste, and appearance, requiring careful management to maintain quality. It is commonly used for thawing large fish and fish blocks (Balachandran, 2001).

Thawing food in still air at ambient or chilled temperatures (0–4°C) is inefficient because of slow heat transfer, taking up to 20 hours to thaw a 100 mm-thick block of frozen cod at 15°C. This method also risks surface dehydration and quality loss, making it unsuitable for industrial use. Air blast thawing, using high airflow and water sprays to maintain humidity, significantly reduces thawing time and prevents dehydration. With proper stacking and airflow management, air blast systems can thaw the same block of cod in 4–4.5 hours (Svendsen *et al.,* 2022).

2. Impingement Thawing:

Impingement is a technique that uses forced airstreams directed at the product's surface through small nozzles. It is well-established in freezing, cooling, and food processing applications like drying. While this method is commonly used in these processes, its use for thawing is still being researched. Some studies have focused on the mathematical aspects of impingement thawing and the determination of heat transfer coefficients, but there is limited experimental research on thawing fish and fishery products. This method appears to offer advantages over traditional thawing methods, especially when surface drying can be avoided, potentially improving thawing efficiency and product quality (Backi, 2018).

3. Vacuum Thawing:

Vacuum thawing operates on the principle that reducing pressure lowers the boiling point of water (3). When steam is introduced into a vacuum chamber at a specific pressure, it condenses on the surface of the fish, releasing heat. This process enables water vapor to penetrate air pockets between fish in the blocks. Precise control of pressure and steam is crucial to prevent heat damage. When properly managed, vacuum thawing achieves thawing speeds comparable to air blast or water thawing. For instance, 65 mm thick shrimp blocks and 50 mm thick plaice blocks can thaw in under 80 minutes. The method is clean, hygienic, and minimizes bacterial contamination, as water condenses only on the product surface, keeping chamber walls dry and requiring minimal cleaning (Backi, 2018).

The material is placed in a chamber where a partial vacuum is created. Steam is then introduced, releasing 2.45 kJ of heat per kilogram as it condenses, rapidly thawing the product. Alternatively, water in a tray at the bottom of the chamber can be heated to generate water vapor, which condenses and transfers heat to the fish (Balachandran, 2001).

4. High Pressure Thawing:

High-pressure thawing relies on the principle that increasing pressure lowers the freezing point of water up to approximately 210 MPa, beyond which the trend reverses. This process takes place in chambers filled with a pressure-transmitting liquid, usually water, with pressure applied through hydraulic systems. Two methods are employed: pressure-assisted thawing, driven by the temperature difference between the pressurized medium and the food, and pressure-induced thawing, which applies pressure along the melting curve of ice. Research-scale applications typically use chamber volumes ranging from 0.05 to 4.57 dm^3, while industrial systems can manage up to 500 dm^3 (Backi, 2018).

High-pressure thawing is a promising innovation in the food industry, offering significantly faster thawing times—up to two-thirds shorter than atmospheric methods—while preserving sensory qualities and reducing drip loss, as demonstrated in beef and tofu. The uniform pressure transmission ensures thawing is unaffected by product size or initial temperature. However, the process faces challenges such as high costs, protein denaturation, and potential meat discoloration. Further research to optimize this method is vital for its broader commercial application (Akhtar *et al.,* 2013).

5. Dielectric Thawing:

Dielectric thawing involves the use of high-frequency waves, such as radio frequency (RF) and microwave techniques, to thaw food products. RF operates in the MHz range, while microwaves work in the GHz range. These methods generate heat by polarizing molecules in an oscillating electric field, with RF waves offering deeper penetration and better suitability for industrial applications, while microwaves are better suited for smaller tasks due to their limited penetration depth. Despite their advantages, these methods face challenges like uneven heating, localized overcooking, and potential damage to packaging materials. Microwave thawing, in particular, can cause thermal runaway in boundary layers, while RF methods provide safer and more uniform heating when managed correctly (Wang *et al.,* 2003; Zhao *et al.,* 2000; Marra *et al.,* 2008).

In practice, dielectric thawing often involves placing the frozen material between two plates that do not directly contact it. These plates are connected to a high-frequency, high-voltage alternating current, generating heat through the motion of charged particles within the product. This process allows for rapid thawing, much faster than conduction heating, especially for homogeneous materials. However, products like fish, which have uneven lipid distribution, may experience localized overheating, causing some areas to thaw while others remain frozen (Balachandran, 2001).

6. Ultrasound Thawing:

Ultrasound thawing is an advanced food defrosting technique using sound waves in the kHz to low MHz range. With longer wavelengths than microwave and radio frequency methods, it allows for deeper penetration and more uniform thawing. Optimal frequencies balance penetration depth and minimize overheating, although improper settings can cause surface overheating. The method requires precise control of parameters like frequency and power to ensure consistent results and avoid uneven heating. Its temperature-dependent attenuation profile enables stable thawing, focusing energy at the frozen-thawed boundary to drive thawing uniformly. This makes ultrasound a promising tool for efficient and rapid defrosting across various food types. (Backi, 2018; Miles *et al.,* 1999).

7. Ohmic Thawing:

Ohmic heating is a process that utilizes electrical current to generate heat directly within food, increasing its temperature rapidly. This technology is particularly advantageous in food processing due to its high energy efficiency and the ability to heat food uniformly without concerns about penetration depth, which is a limitation in other methods like microwaving. The technique relies on the electrical resistance of the food, and heat is generated throughout the product rather than just on the surface. In addition to faster heating rates, ohmic heating allows for precise temperature control, making it suitable for a range of food applications such as pasteurization, sterilization, and thawing. The method also offers better water retention and reduced drip loss in thawed products, contributing to improved product quality. Furthermore, ohmic heating provides high volumetric heating, meaning that the entire food mass is heated simultaneously, reducing the risk of overheating certain areas. Despite its potential, the efficiency of ohmic heating depends on factors like voltage, frequency, and food composition (Akhtar *et al.,* 2013).

8. Acoustic Thawing:

The use of acoustic energy for thawing frozen foods has been explored for decades, but early challenges such as poor penetration, localized heating, and high power requirements limited its development (Brody & Antenevich, 1959). Recent studies on the relaxation mechanisms of ice crystals indicate that frozen foods can absorb more acoustic energy when exposed to frequencies within the relaxation range of ice crystals. It has been found that applying specific acoustic frequencies can reduce thawing time significantly. High-power ultrasound, particularly at frequencies around 500 kHz, has been shown to be effective for thawing meat and fish. Acoustic thawing holds promise as an efficient technique in the food industry, especially when optimal frequencies and power levels are selected (Akhtar *et al.,* 2013).

9. Electrical Resistance Thawing:

Electrical resistance thawing, also known as Ohmic or Joule heating, works by generating heat inside food when electric current passes through it, due to the electrical resistance of the food. The thawing time is faster with lower resistance. Initially, conventional thawing methods are preferred for frozen food, as it has high resistance at low temperatures. Once the resistance decreases, electrical resistance thawing becomes effective. This method is efficient because almost all energy is converted into heat, and there is no limitation on penetration depth. However, it may cause local overheating, so the food should have a regular shape for optimal results (Backi, 2018).

Electrical resistance thawing involves passing an electric current through the product, generating heat as a result of the food's electrical resistance. The product is positioned between two electrodes, with proper electrical contact being crucial for efficient operation. The energy typically used in this process is alternating voltage, commonly at a frequency of 50 Hz and 220 V. This method leverages the resistance of the food to heat it uniformly, making it a viable technique for thawing, with the effectiveness largely dependent on the quality of the electrical connection and the resistance of the product (Haugland, 2002).

10. Far-Infrared (Fir) Thawing:

Far-infrared (FIR) thawing operates on similar principles as dielectric thawing, but with higher frequencies and shorter wavelengths than microwaves, as FIR waves fall within a spectrum just beyond microwaves. It can serve as an alternative to microwave thawing (Sakai & Hanzawa, 1994). Despite its higher frequencies, FIR thawing reduces the risk of local overheating (thermal runaway) because the absorption coefficients of FIR waves for both ice and water are nearly identical. However, FIR waves have even shallower penetration depths compared to microwaves, which can lead to localized overheating, especially in thicker food items (Backi, 2018).

Product Quality:

The quality of fish after thawing is influenced by several factors, including texture, sensory properties, color, pH, water and fat content, water holding capacity, and drip loss. Drip loss, color, and texture are commonly analyzed parameters in many studies, though other factors like odor, flavor, and chemical composition also contribute to overall quality (Olafsdottir *et al.,* 1997). The impact of freezing and thawing methods on food quality, especially for meat products, has been well-documented, with studies focusing on aspects such as moisture loss, protein denaturation, and lipid oxidation (Leygonie *et al.,* 2012).

However, similar comprehensive studies on fish products are limited. Thawing methods significantly influence quality attributes, with water thawing generally preserving the best quality in various species (Ersoy *et al.,* 2008). Thawing time and rate significantly influence moisture loss in meat, with faster thawing typically reducing drip loss. Shorter thawing times allow water to be absorbed into dehydrated fibers, minimizing exudate formation. Methods like water submersion thawing are effective in reducing drip loss, while microwave thawing tends to cause higher moisture loss compared to slower methods like refrigerator thawing (Akhtar *et al.,* 2013).

Conclusion:

Thawing is a crucial process in the food industry, especially for perishable products like fish. The choice of thawing method can significantly impact the quality, safety, and sensory properties of the product. Different thawing techniques, both thermal and non-thermal, offer distinct advantages and challenges in terms of efficiency, quality retention, and cost. Thermal methods, such as microwave and dielectric thawing, offer speed but can lead to uneven heating and localized overcooking, especially in products with uneven texture like fish. Non-thermal methods, such as vacuum, ultrasound, and high-pressure thawing, preserve better product quality but may face challenges like complexity, high costs, and longer processing times. Additionally, the thawing rate and method selected directly influence important quality attributes such as moisture retention, texture, color, and drip loss.

For optimal results, methods like water thawing generally yield the best product quality by minimizing moisture loss and preserving texture, while newer methods like vacuum and ultrasound thawing are being explored for their potential to maintain quality while reducing thawing time. Ultimately, the selection of a thawing method should consider the type of product, the desired quality outcomes, and the operational constraints of the food processing system. Continued research into improving thawing techniques and understanding their effects on fish and other foods will be critical for optimizing quality, reducing energy consumption, and ensuring safety in the food supply chain.

References:

1. Akhtar, S., Khan, M. I., & Faiz, F. (2013). Effect of thawing on frozen meat quality: A comprehensive review. *Pakistan Journal of Food Sciences*, *23*(4), 198-211.

2. Balachandran, K. K. (2001). *Post-harvest technology of fish and fish products*. Daya Books.
3. Backi, C. J. (2018). Methods for (industrial) thawing of fish blocks: A review. *Journal of Food Process Engineering*, *41*(1), e12598.
4. Brody, A. L., & Antenevich, J. N. (1959). Ultrasonic defrosting of frozen foods. *Food Technology*, *13*(2), 109-112.
5. Cai, L., Cao, M., Regenstein, J., & Cao, A. (2019). Recent advances in food thawing technologies. *Comprehensive Reviews in Food Science and Food Safety*, *18*(4), 953-970.
6. Ersoy, B., Aksan, E., & Özeren, A. (2008). The effect of thawing methods on the quality of eels (Anguilla anguilla). *Food chemistry*, *111*(2), 377-380.
7. Haugland, A. (2002). Industrial thawing of fish: to improve quality, yield and capacity.
8. Leygonie, C., Britz, T. J., & Hoffman, L. C. (2012). Impact of freezing and thawing on the quality of meat. *Meat science*, *91*(2), 93-98.
9. Marra, F., Zhang, L., & Lyng, J. G. (2009). Radio frequency treatment of foods: Review of recent advances. *Journal of food engineering*, *91*(4), 497-508.
10. Miles, C. A., Morley, M. J., & Rendell, M. (1999). High power ultrasonic thawing of frozen foods. *Journal of Food Engineering*, *39*(2), 151-159.
11. Olafsdottir, G., Martinsdóttir, E., Oehlenschläger, J., Dalgaard, P., Jensen, B., Undeland, I., ... & Nilsen, H. (1997). Methods to evaluate fish freshness in research and industry. *Trends in food science & technology*, *8*(8), 258-265.
12. Sakai, N., & Hanzawa, T. (1994). Applications and advances in far-infrared heating in Japan. *Trends in Food Science & Technology*, *5*(11), 357-362.
13. Svendsen, E. S., Widell, K. N., Tveit, G. M., Nordtvedt, T. S., Uglem, S., Standal, I., & Greiff, K. (2022). Industrial methods of freezing, thawing and subsequent chilled storage of whitefish. *Journal of Food Engineering*, *315*, 110803.
14. Wang, Y., Wig, T. D., Tang, J., & Hallberg, L. M. (2003). Dielectric properties of foods relevant to RF and microwave pasteurization and sterilization. *Journal of Food Engineering*, *57*(3), 257-268.
15. Zhao, Y., Flugstad, B. E. N., Kolbe, E., Park, J. W., & Wells, J. H. (2000). Using capacitive (radio frequency) dielectric heating in food processing and preservation–a review. *Journal of Food Process Engineering*, *23*(1), 25-55.

SMART FOOD PACKAGING: USE, IMPLEMENTATION AND CHALLENGES

Manoj Patidar

Department of Zoology,

PM College of Excellence, Govt. PG College Khargone

& Govt. College Manawar, Madhya Pradesh, India

Corresponding author E-mail: manoj1patidar@gmail.com

Abstract:

Smart food packaging represents a significant advancement that merges innovative technology with traditional materials to meet the increasing demands for food safety, freshness, sustainability, and convenience. In contrast to standard packaging, smart packaging incorporates elements such as sensors, time-temperature indicators, and active components that actively monitor and react to environmental conditions, including temperature, humidity, and oxygen levels. These technological enhancements not only aid in maintaining food quality by prolonging shelf life but also furnish consumers with essential real-time information regarding the product's freshness, storage conditions, and even its source. For instance, time-temperature indicators can alert consumers when a product has been subjected to adverse conditions, while oxygen scavengers work to inhibit spoilage by removing excess air. Furthermore, advancements such as biodegradable materials and edible packaging play a vital role in minimizing the ecological footprint of food packaging. As consumer preferences increasingly lean towards transparency, healthier alternatives, and environmentally friendly options, smart packaging is essential in reshaping the food industry, providing a more sustainable, efficient, and consumer-focused approach.

Keywords: Food Packaging, Sensors, Nanotechnology, Safety Monitoring

Introduction:

Smart food packaging represents a significant advancement that merges innovative technology with traditional materials to meet the increasing demands for food safety, freshness, sustainability, and convenience. In contrast to standard packaging, smart packaging incorporates elements such as sensors, time-temperature indicators, and active components that actively monitor and react to environmental conditions, including temperature, humidity, and oxygen levels [1]. These technological enhancements not only aid in maintaining food quality by prolonging shelf life but also furnish consumers with essential real-time information regarding the product's freshness, storage conditions, and even its source. For instance, time-temperature indicators can alert consumers when a product has been subjected to adverse conditions, while oxygen scavengers work to inhibit spoilage by removing excess air [2]. Furthermore, advancements such as biodegradable materials and edible packaging play a vital role in minimizing the ecological footprint of food packaging. As consumer preferences increasingly lean towards transparency, healthier alternatives, and environmentally friendly options, smart packaging is essential in reshaping the food industry, providing a more sustainable, efficient, and consumer-focused approach [3]. The evolution of smart packaging technology in the food sector has resulted in notable enhancements in food safety, preservation, and sustainability, fundamentally transforming the industry. This progress is fueled by the incorporation of advanced technologies and innovations in materials science, enabling packaging to transition from a mere protective barrier to an interactive system that engages with both the food items and their surrounding environment. Below are several significant advancements in smart food packaging [4].

Active Food Packaging:

Active food packaging refers to innovative packaging systems that are engineered to interact with the food they contain, thereby enhancing shelf life, preserving quality, and maintaining freshness by responding adaptively to both internal and external environmental factors [5]. Unlike traditional packaging, which primarily functions as a protective barrier, active packaging possesses the ability to modify the internal atmosphere of the package or directly engage with the food item. This capability is enabled by various elements, including oxygen scavengers that remove excess oxygen to reduce oxidation and spoilage, as well as moisture regulators that ensure optimal humidity levels, preventing products such as baked goods and chips from becoming stale [6]. Other notable components include ethylene absorbers, which slow down the ripening of fruits and vegetables, and antimicrobial agents that inhibit the growth of bacteria and fungi, thereby extending the shelf life of food products. Active packaging not only enhances food preservation but also significantly contributes to the reduction of food waste by keeping products fresh for longer durations, marking a vital development in the food industry [7].

Intelligent Food Packaging with Sensors:

Intelligent food packaging that incorporates sensors represents a significant advancement in the integration of sophisticated sensing technologies within packaging materials, aimed at monitoring and responding to environmental changes affecting food products. These sensors are capable of detecting essential parameters such as temperature, humidity, pH levels, and the presence of gases, including oxygen and carbon dioxide, all of which play a crucial role in determining the freshness and safety of food items [8]. For example, time-temperature indicators (TTIs) integrated into the packaging can alter their color or issue alerts when the product is subjected to inappropriate temperature conditions, thereby informing consumers or retailers of potential quality concerns. Additionally, gas sensors can track the emission of gases such as carbon dioxide or ethylene, which are released during the processes of ripening or spoilage, thus providing valuable information regarding the freshness of fruits, vegetables, or meat products [9]. These intelligent packaging systems deliver real-time data that aids in prolonging shelf life, minimizing food waste, and ensuring that products are consumed while they are at their peak freshness. Moreover, they facilitate improved inventory management and traceability throughout the supply chain, thereby enhancing food safety and quality assurance [10].

Biodegradable and Sustainable Materials for Food Packaging:

Biodegradable and sustainable materials for food packaging are increasingly recognized as viable solutions to the environmental issues associated with conventional plastic packaging. These materials originate from renewable, natural resources such as plant starch, cellulose, seaweed, and polylactic acid (PLA), providing an environmentally friendly alternative that can decompose naturally without leaving toxic residues [11]. Innovations such as plant-based films and edible coatings aim to replace single-use plastics, thereby decreasing plastic waste and lessening environmental harm. In contrast to traditional packaging, which can endure in landfills for centuries, biodegradable materials decompose more rapidly, enhancing their sustainability over time. Furthermore, advancements in compostable packaging enable consumers to dispose of materials in a more responsible manner, thereby supporting a circular economy [12]. These alternatives not only aid in waste reduction but also typically require less energy for production compared to petroleum-derived plastics, which further diminishes their carbon footprint. As the demand for environmentally conscious options continues to grow, biodegradable and sustainable food packaging is emerging as a significant catalyst for transformation within the food industry [13-14].

Radio Frequency Identification and Blockchain Integration for Food Packaging:

The incorporation of Radio Frequency Identification (RFID) technology alongside blockchain into food packaging is revolutionizing the methods by which food is tracked, authenticated, and monitored throughout its lifecycle, from production to consumption. RFID employs compact, wireless tags embedded within packaging that can capture and relay critical information regarding a product, including its source, storage conditions, and shelf life [15]. This technology facilitates real-time tracking, thereby enhancing inventory management and providing improved oversight of the supply chain. When integrated with blockchain, the data obtained from RFID tags is securely recorded in a decentralized ledger, which guarantees transparency and traceability that is resistant to alteration or fraud [15]. Blockchain establishes a permanent and immutable record of each transaction within the supply chain, encompassing all stages from production to distribution and retail. This synergy not only bolsters food safety by enabling rapid identification and resolution of issues such as spoilage or contamination but also equips consumers with verified information about their food purchases, thereby promoting trust and accountability. Collectively, RFID and blockchain technologies strengthen food security, minimize waste, and contribute to the development of more sustainable and transparent food systems [16].

Nanotechnology in Food Packaging:

Nanotechnology in food packaging refers to the application of nanoparticles and nanomaterials to improve the characteristics of packaging materials, thereby enhancing their functionality and effectiveness in maintaining food quality and safety. The integration of nanoscale materials, such as nanocomposites and nano-coatings, results in superior barrier properties that protect food products from oxygen, moisture, light, and microbial contamination more efficiently than conventional packaging solutions [17]. These advancements contribute to prolonged shelf life and the retention of food freshness. Furthermore, nanotechnology facilitates the creation of antimicrobial packaging, which can prevent the proliferation of harmful bacteria and fungi, thereby bolstering food safety. Additionally, the incorporation of nanomaterials allows for the implementation of nano-sensors that monitor internal packaging conditions, detecting variations in gas concentrations or temperature and providing real-time insights into the state of the food [18]. This synergy of enhanced functionalities not only improves food preservation but also enables the production of lighter, stronger, and more environmentally sustainable packaging materials, ultimately reducing the overall ecological footprint.

Self-Healing Packaging:

Self-healing food packaging technology represents a groundbreaking advancement that significantly improves the durability and functionality of food containers by allowing them to autonomously mend minor damages, such as small tears or punctures. This capability is facilitated by the incorporation of sophisticated materials, including self-healing polymers or microcapsules embedded within the packaging structure [29]. When the packaging sustains damage, these microcapsules release healing agents that activate upon detecting a tear or crack, effectively bonding the edges of the damage and restoring the packaging's integrity. This innovative technology not only preserves the structural soundness of the packaging but also acts as a barrier against contamination and spoilage by preventing the ingress of external factors such as bacteria, oxygen, and moisture [20]. By mitigating the likelihood of leaks and compromised protective barriers, self-healing packaging enhances the shelf life of food products and bolsters their safety. Furthermore, this technology contributes to the reduction of food waste and lessens the reliance on excessive packaging materials, thereby promoting more sustainable practices in food packaging solutions.

Food Safety Monitoring:

Food safety monitoring through the use of smart labels represents a cutting-edge strategy for maintaining the integrity and safety of food items by incorporating sophisticated technologies into their packaging. These labels are designed with sensors capable of monitoring various parameters, including temperature, humidity, and indicators of bacterial contamination or spoilage [21]. For example, temperature-sensitive smart labels can alter their color or issue alerts if food products are subjected to unsafe temperature conditions during storage or transportation, thereby notifying consumers or retailers of potential spoilage risks. Similarly, pH-sensitive labels can assess the acidity levels in perishable items such as seafood or dairy, providing alerts for any fluctuations that may suggest microbial proliferation [22]. Furthermore, certain smart labels are integrated with bacterial detection mechanisms that can change color in the presence of pathogens, delivering real-time assessments of food safety. By offering immediate visual cues regarding the state of food products, these labels play a crucial role in mitigating foodborne illnesses, minimizing waste, and enhancing the overall consumer experience, thereby ensuring that food items are both safe for consumption and of superior quality.

Conclusion and Future Perspectives:

Food packaging technology has undergone significant advancements in recent years, transitioning from basic protective materials to complex systems that enhance food safety, prolong shelf life, and foster sustainability [23]. Innovations such as smart packaging, active and intelligent systems, biodegradable materials, and nanotechnology have greatly improved the preservation, tracking, and delivery of food products to consumers. These developments not only minimize food waste and improve product quality but also promote transparency, sustainability, and environmentally friendly practices within the food sector. Looking ahead, the field of food packaging is set for further evolution, with the potential for more advanced materials, enhanced integration of artificial intelligence and machine learning to optimize packaging systems, and a greater emphasis on fully biodegradable and edible packaging options [24]. Ongoing research into self-healing, interactive, and energy-efficient packaging is expected to render food packaging smarter, more adaptive, and increasingly sustainable. As consumer preferences shift towards transparency, convenience, and sustainability, the future of food packaging is likely to witness a merging of technological innovation and environmental awareness, resulting in more efficient, safer, and eco-friendly packaging solutions [25-26].

Acknowledgment:

The author acknowledges the Department of Higher Education, Govt. of Madhya Pradesh, Principal, and IQAC head, PMCoE Govt PG College Khargone and Govt. College Manawar.

References:

1. Yousefi, H., Su, H. M., Imani, S. M., Alkhaldi, K., M Filipe, C. D., & Didar, T. F. (2019). Intelligent Food Packaging: A Review of Smart Sensing Technologies for Monitoring Food Quality. ACS sensors, 4(4), 808–821.
2. Biji, K.B., Ravishankar, C.N., Mohan, C.O. *et al.* (2015). Smart packaging systems for food applications: a review. J Food Sci Technol 52, 6125–6135.
3. Drago, E., Campardelli, R., Pettinato, M., & Perego, P. (2020). Innovations in Smart Packaging Concepts for Food: An Extensive Review. *Foods*, *9*(11), 1628.
4. Young, Erin & Mirosa, Miranda & Bremer, Phil. (2020). A Systematic Review of Consumer Perceptions of Smart Packaging Technologies for Food. Frontiers in Sustainable Food Systems. 4. 63. 10.3389/fsufs.2020.00063.
5. OZDEMIR, M., & FLOROS, J. D. (2004). Active Food Packaging Technologies. *Critical Reviews in Food Science and Nutrition*, *44*(3), 185–193.

6. Gómez-Estaca, Joaquín & Lopez de Dicastillo, Carol & Hernández-Muñoz, Pilar & Catala, Ramon & Gavara, Rafael. (2013). Advances in antioxidant active food packaging. Trends in Food Science & Technology. 35. 10.1016/j.tifs.2013.10.008.
7. Rooney, Michael. (2012). Introduction to Active Food Packaging Technologies. Plastic Films in Food Packaging: Materials, Technology and Applications. 127-138. 10.1016/B978-1-4557-3112-1.00008-9.
8. Vanderroost, Mike & Ragaert, Peter & Devlieghere, Frank & Meulenaer, Bruno. (2014). Intelligent food Packaging: The next generation. Trends in Food Science & Technology. 39. 10.1016/j.tifs.2014.06.009.
9. Puligundla, Pradeep & Jung, Junho & Ko, Sanghoon. (2012). Carbon dioxide sensors for intelligent food packaging applications. Food Control. 25. 10.1016/j.foodcont.2011.10.043.
10. Matindoust, Samaneh & Baghaei Nejad, Majid & Shahrokh Abadi, M.H. & Zou, Zhuo & Zheng, Li-Rong. (2016). Food quality and safety monitoring using gas sensor array in intelligent packaging. Sensor Review. 36. 169-183. 10.1108/SR-07-2015-0115.
11. Wróblewska-Krepsztul, J., Rydzkowski, T., Borowski, G., Szczypiński, M., Klepka, T., & Thakur, V. K. (2018). Recent progress in biodegradable polymers and nanocomposite-based packaging materials for sustainable environment. *International Journal of Polymer Analysis and Characterization*, *23*(4), 383–395.
12. Mahpuz, Ahmad & Sanusi, Nurul & Jusoh, Aliya & Amin, Nurul & Musa, Nur & Sarabo, Zulaikha & Othman, Nor. (2022). Manifesting sustainable food packaging from biodegradable materials: A review. Environmental Quality Management. 32. 10.1002/tqem.21859.
13. Jahangiri, Fatemeh & Mohanty, Amar & Misra, Manjusri. (2024). Sustainable biodegradable coatings for food packaging: challenges and opportunities. Green Chemistry. 26. 10.1039/D3GC02647G.
14. Sainsonas de Andrade, Marcio & Ishikawa, Otávio & Costa, Robson & Seixas, Marcus & Rodrigues, Rita & Moura, Esperidiana. (2022). Development of sustainable food packaging material based on biodegradable polymer reinforced with cellulose nanocrystals. Food Packaging and Shelf Life. 31. 100807. 10.1016/j.fpsl.2021.100807.
15. Deng, M. and Feng, P. (2020) A Food Traceability System Based on Blockchain and Radio Frequency Identification Technologies. *Journal of Computer and Communications*, **8**, 17-27.

16. Zou, Z., Chen, Q., Uysal, I., & Zheng, L. (2014). Radio frequency identification enabled wireless sensing for intelligent food logistics. *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences*, *372*(2017), 20130313.
17. Primožič, M., Knez, Ž., & Leitgeb, M. (2021). (Bio)nanotechnology in Food Science-Food Packaging. *Nanomaterials (Basel, Switzerland)*, *11*(2), 292.
18. Cerqueira, Miguel & Vicente, António & Pastrana, Lorenzo. (2018). Nanotechnology in Food Packaging: Opportunities and Challenges. 10.1016/B978-0-323-51271-8.00001-2.
19. Huang, Kehao & Wang, Yixiang. (2022). Recent advances in self-healing materials for food packaging. Packaging Technology and Science. 36. 10.1002/pts.2701.
20. Wang, J., Gao, Q., Zhao, F., & Ju, J. (2024). Repair mechanism and application of self-healing materials for food preservation. *Critical reviews in food science and nutrition*, *64*(30), 11113–11123.
21. Weng, Xuan & Neethirajan, Suresh. (2017). Ensuring Food Safety: Quality Monitoring Using Microfluidics. Trends in Food Science & Technology. 65. 10.1016/j.tifs.2017.04.015.
22. Jonge, Janneke & Frewer, Lynn & Trijp, Hans & Renes, Reint & Wit, Willem & Timmers, Joke. (2004). Monitoring consumer confidence in food safety: An exploratory study. British Food Journal. 106. 837-849. 10.1108/00070700410561423.
23. Rydz, Joanna & Musioł, Marta & Zawidlak-Węgrzyńska, Barbara & Sikorska, Wanda. (2018). Present and Future of Biodegradable Polymers for Food Packaging Applications. 10.1016/B978-0-12-811449-0.00014-1.
24. Han, J. W., Ruiz-Garcia, L., Qian, J. P., & Yang, X. T. (2018). Food Packaging: A Comprehensive Review and Future Trends. *Comprehensive reviews in food science and food safety*, *17*(4), 860–877.
25. Majid, Ishrat & Nayik, Gulzar & Dar, Shuaib & Nanda, Vikas. (2016). Novel food packaging technologies: Innovations and future prospective. Journal of the Saudi Society of Agricultural Sciences. 17. 10.1016/j.jssas.2016.11.003.
26. Chadha, Utkarsh & Bhardwaj *et al.* (2022). Current Trends and Future Perspectives of Nanomaterials in Food Packaging Application. Journal of Nanomaterials. 2022. 1-32. 10.1155/2022/2745416.

ROLE OF ANTHELMINTIC DRUGS IN FOOD PRODUCTS FOR CHILDREN

Nirmal Shah*, Dipti Gohil, Sunil Kardani and Yashrajsinh Jadeja

Department of Pharmacy,

Sumandeep Vidyapeeth Deemed to be University, Piparia, Vadodara, Gujarat

*Corresponding author E-mail: nimspharma@gmail.com

Abstract:

The presence of intestinal worms in children is a significant global health concern, particularly in developing regions where access to sanitation and healthcare is limited. Anthelmintic drugs play a critical role in treating and preventing parasitic infections, which can lead to malnutrition, stunted growth, and cognitive impairments in young populations. This chapter explores the integration of anthelmintic drugs in food products designed for children, evaluating their safety, efficacy, and regulatory considerations. It examines the potential benefits of fortifying food with anthelmintics as a proactive measure against parasitic infections, especially in endemic areas. Additionally, the chapter addresses challenges in ensuring proper dosing, avoiding resistance development, and ensuring that food products remain palatable and nutritious for children. By balancing effectiveness with safety, the chapter aims to offer insight into how anthelmintic drugs can be incorporated into food products to improve public health outcomes for children worldwide.

Keywords: Intestinal Worms, Anthelmintic Drugs, Food Products, Palatability

Introduction:

Parasitic infections in children remain a significant global health concern, particularly in low- and middle-income countries where sanitation and healthcare access are limited. These infections are caused by a variety of parasites, including roundworms, hookworms, tapeworms, and protozoa, which affect millions of children worldwide. The World Health Organization (WHO) estimates that over 1.5 billion people, or nearly a quarter of the world's population, suffer from some form of parasitic infection, with children being particularly vulnerable due to their developing immune systems and higher susceptibility to poor hygiene and contaminated environments.

The consequences of parasitic infections in children can be severe and long-lasting. Intestinal worms, for example, can lead to malnutrition by impairing the absorption of nutrients, contributing to stunted growth, cognitive delays, and anemia. These infections often exacerbate existing health problems and prevent children from reaching their full physical and cognitive potential. In addition to these direct effects, parasitic diseases place a strain on healthcare systems, leading to lost productivity in communities and high economic costs related to treatment, prevention, and lost school attendance.

Children living in areas with poor sanitation, limited access to clean water, and inadequate health education are at the highest risk. These children are often exposed to contaminated food, water, and soil, which serve as transmission routes for parasites. For example, hookworm infections are commonly contracted when children walk barefoot on contaminated soil, while roundworm and tapeworm infections are often linked to the consumption of undercooked or contaminated food.

Furthermore, these infections are cyclical in nature—once a child is infected, they may face repeated reinfections due to the persistence of parasites in the environment, further hindering development and well-being. The stigma surrounding these infections and the lack of widespread public health education also contribute to the challenge of tackling parasitic diseases in children.

Despite these challenges, several global initiatives, including mass deworming campaigns and the use of anthelmintic drugs, have shown promise in reducing the burden of parasitic infections. However, the widespread implementation of such measures remains a work in progress, and more needs to be done to address the root causes, improve access to effective treatments, and ensure that children in affected regions receive the necessary care to prevent and treat these infections [1, 2].

Importance of anthelmintic drugs in treating parasitic infections

Anthelmintic drugs are crucial in combating parasitic infections, particularly those caused by intestinal worms, which are widespread in many developing regions of the world. These medications help to treat and manage infections by either killing or inhibiting the growth of parasitic worms. The importance of anthelmintic drugs in treating parasitic infections in children, in particular, cannot be overstated, as they offer several significant benefits[3-5]:

Effective Treatment of Common Parasitic Worms

Anthelmintic drugs are designed to target a wide range of parasitic worms, including roundworms, hookworms, tapeworms, and whipworms. These infections are particularly prevalent in children, who are more susceptible due to their developing immune systems and behaviors like playing in contaminated environments. Anthelmintics, such as albendazole, mebendazole, and praziquantel, are among the most widely used treatments, and they are effective in eliminating these parasites from the body, thus relieving the associated symptoms and preventing complications.

Prevention of Malnutrition and Growth Impairment

Parasitic worms often interfere with nutrient absorption in the intestines, leading to malnutrition and stunted growth, especially in young children. By effectively clearing these worms from the body, anthelmintic drugs can improve nutritional status, promote proper growth, and prevent long-term developmental delays. In areas where undernutrition is already a concern, treating parasitic infections with anthelmintics can play a key role in breaking the cycle of malnutrition and promoting healthier, more productive futures for children.

Improvement of Cognitive Function

Beyond physical growth, parasitic infections can also affect a child's cognitive abilities. Worm infestations have been linked to impaired cognitive development and reduced school performance due to the chronic fatigue and anemia they cause. Anthelmintic treatments can help reduce the incidence of cognitive impairments by eliminating the parasites, thereby improving a child’s overall learning capacity and academic outcomes.

Reduction of Disease Transmission

Anthelmintic drugs do not only benefit the individual receiving the treatment but can also help reduce the transmission of parasitic infections within communities. By treating children and adults in endemic areas, mass deworming programs can significantly lower the overall parasite load, thereby reducing the risk of reinfection and the spread of worms to other people. This communal approach is vital in controlling the spread of parasitic diseases in areas with high prevalence rates.

Cost-Effectiveness and Accessibility

Many anthelmintic drugs are relatively inexpensive and accessible, making them a cost-effective solution for managing parasitic infections in resource-poor settings. This accessibility has enabled widespread deworming programs in schools and communities, helping to reduce the burden of parasitic diseases, especially in low-income countries. The availability of generic forms of anthelmintics has further improved their reach, making them a viable option for large-scale public health initiatives.

Prevention of Long-Term Health Complications

Chronic parasitic infections can lead to long-term health complications such as anemia, vitamin deficiencies, and irreversible damage to organs, particularly in the case of certain species of tapeworms or liver flukes. Anthelmintic treatment helps prevent these long-term effects by eradicating the parasites before they cause permanent damage, thus improving overall health outcomes.

Promoting Public Health and Development

The widespread use of anthelmintic drugs, particularly in school-based mass deworming programs, has been linked to improved public health and economic development. By reducing the incidence of parasitic infections, children are more likely to stay in school, perform well academically, and grow into healthy adults who can contribute to their communities. This, in turn, can have a positive impact on national economies, particularly in regions where parasitic infections are a major barrier to human development.

Rationale for incorporating anthelmintic drugs into food products for children

The incorporation of anthelmintic drugs into food products for children represents an innovative approach to tackling the widespread problem of parasitic infections, particularly in areas where these infections are endemic. This strategy is gaining attention due to its potential to improve access to treatment, enhance compliance, and support broader public health goals. Below are key reasons for considering the integration of anthelmintic drugs into food products for children[6-8]:

Improved Access to Treatment

In many parts of the world, access to healthcare services is limited, particularly in rural or low-income areas. Children may face difficulties accessing healthcare due to logistical barriers, financial constraints, or a lack of trained healthcare professionals. By incorporating anthelmintic drugs into commonly consumed food products, such as fortified snacks, biscuits, or porridge, children can receive treatment in a more accessible and convenient manner. This reduces the need for healthcare visits and allows for a broader reach of the medication, especially in communities where formal healthcare infrastructure is insufficient.

Increased Compliance and Adherence to Treatment

One of the challenges in deworming programs is ensuring that children complete their treatment regimen. Traditional methods of delivering medications, such as pills or syrups, often face barriers like the child's reluctance to take medicine, unpleasant taste, or forgetfulness. Incorporating anthelmintics into food products eliminates many of these barriers, as children are more likely to consume foods that are palatable and familiar to them. This method enhances adherence to treatment, ensuring that children receive the necessary doses to clear the parasitic infections.

Proactive and Preventative Approach

Incorporating anthelmintics into food products can shift the focus from reactive treatment to proactive prevention. By fortifying food with anthelmintic drugs, children may receive regular, low-dose treatment as part of their daily nutrition. This is especially beneficial in regions where children are at high risk of repeated infections due to poor sanitation, contaminated water, and inadequate hygiene practices. Regular, preventive treatment can help reduce the prevalence of parasitic infections over time and lower the incidence of reinfection, improving long-term health outcomes.

Mass Deworming through Food-Based Interventions

Mass deworming campaigns have proven effective in reducing the burden of parasitic infections, particularly in school-aged children. Incorporating anthelmintics into food products provides an opportunity to extend the reach of mass deworming programs to children outside of the school environment. School-based programs have limitations in terms of outreach, but food-based interventions can reach children who are not enrolled in school, including those in rural and marginalized communities. This broader reach helps ensure that more children benefit from deworming efforts.

Reduced Risk of Side Effects and Overdosing

In traditional deworming programs, proper dosing is critical to avoid underdosing (which can lead to ineffective treatment) or overdosing (which can cause harmful side effects). Integrating anthelmintic drugs into food products can simplify the dosing process, especially when combined with fortification strategies that offer controlled amounts of the drug. This reduces the risk of incorrect dosing, ensuring that children receive safe and effective treatment without the risks associated with improper administration.

Targeting Nutritional Deficiencies in Children

Parasitic infections, particularly those caused by intestinal worms, often result in malnutrition and nutrient deficiencies due to the impaired absorption of essential vitamins and minerals. Incorporating anthelmintic drugs into fortified food products can simultaneously address nutritional deficiencies while treating parasitic infections. This dual-purpose intervention can improve overall health by preventing malnutrition, supporting growth and development, and enhancing the immune system, all of which are particularly important during the early years of a child's life.

Sustainability and Cost-Effectiveness

The fortification of food products with anthelmintic drugs offers a cost-effective and sustainable solution to addressing parasitic infections. While the upfront costs of developing fortified food products may be high, they can lead to long-term savings by reducing the need for frequent treatments, preventing the development of more severe health complications, and improving overall productivity and economic outcomes. Food-based interventions also have the potential to be scalable, particularly if supported by local food production systems.

Community Health Impact

Food-based interventions that incorporate anthelmintic drugs can have a positive impact on community health. Regularly treated children are less likely to spread infections to their peers or family members, thereby helping to reduce the overall burden of parasitic infections in the community. As more children are treated in this way, the overall prevalence of parasitic infections can decrease, resulting in improved health and economic outcomes for entire communities.

Building on Existing Food Systems

Many regions with high rates of parasitic infections already have established food distribution systems, such as school meal programs or community-based feeding initiatives. Incorporating anthelmintics into these existing food products allows for efficient distribution without the need for creating entirely new infrastructure. By leveraging existing networks, it becomes easier to ensure that a large number of children receive regular and consistent treatment.

Enhancing Global Health Initiatives

The incorporation of anthelmintic drugs into food products aligns with global health initiatives aimed at improving child health and reducing the burden of neglected tropical diseases (NTDs). Programs like the WHO's "Sustainable Development Goals" and other global health initiatives recognize the need for integrated solutions to tackle multiple health issues simultaneously. By incorporating anthelmintic drugs into food products, countries can take a holistic approach to improving child health and contributing to the broader effort of controlling parasitic infections worldwide.

In summary, incorporating anthelmintic drugs into food products for children presents a promising solution to combating parasitic infections. It ensures improved access to treatment, increases compliance with medication regimens, and provides a preventive approach to controlling parasitic diseases. This strategy not only addresses the immediate health concerns related to parasitic infections but also promotes long-term health, nutritional benefits, and socio-economic development, particularly in high-risk communities.

Mechanisms of Action of Anthelmintics

Anthelmintic drugs are designed to target and eliminate parasitic worms (helminths) that infect humans and animals. These drugs work by interfering with the biological processes of the parasites, ultimately leading to their death or expulsion from the host's body. Different classes of anthelmintic drugs utilize various mechanisms to disrupt the parasite's life cycle. Below are the primary mechanisms of action for the most commonly used anthelmintic [9-12].

- Disruption of Microtubule Function
- Interference with Neuromuscular Function
- Inhibition of Energy Production
- Disruption of the Worm's Protective Coat
- Enhancing the Immune Response
- Inhibition of Folic Acid Metabolism
- Alteration of the Blood-Brain Barrier in Parasites
- Inhibition of Worm Reproduction

The mechanisms of action of anthelmintic drugs are varied and target specific biological functions within the parasite. Whether by disrupting microtubules, interfering with neuromuscular function, blocking energy production, or damaging the parasite's protective membranes, these drugs offer powerful tools for controlling parasitic infections in humans. The development and use of these drugs are essential in global efforts to combat neglected tropical diseases, reduce morbidity, and improve health outcomes, particularly for children living in regions with high rates of parasitic infection.

Common Anthelmintic Drugs Used in Pediatric Treatments

Anthelmintic drugs are critical in the treatment and control of parasitic infections in children, especially in regions where intestinal worms (helminths) are prevalent. These medications are typically used to target a variety of worms, including roundworms, hookworms, tapeworms, and whipworms. Below is a list of some of the most commonly used anthelmintic drugs for pediatric treatments, along with a brief description of each[13-14].

- Albendazole
- Mebendazole
- Pyrantel Pamoate
- Levamisole
- Praziquantel
- Diethylcarbamazine (DEC)
- Ivermectin
- Niclosamide

Prevalence of Parasitic Infections in Children

Parasitic infections remain a significant public health issue, particularly in developing regions of the world. Children are especially vulnerable to these infections due to factors such as poor sanitation, inadequate access to clean water, and limited healthcare resources. The impact of parasitic infections on children includes both immediate and long-term health effects, such as malnutrition, stunted growth, impaired cognitive development, and weakened immune systems. Below is an overview of the prevalence of parasitic infections in children globally, with a focus on the most common types of parasitic diseases affecting this population[15-16].

Parasitic infections are a major health concern for children worldwide, particularly in areas with poor sanitation and healthcare infrastructure. The prevalence of these infections can lead to significant health issues, including malnutrition, stunted growth, developmental delays, and high mortality. However, with increased public health interventions, such as mass deworming programs, improved sanitation, and access to effective treatments, the prevalence of parasitic infections in children can be reduced, leading to better overall health outcomes.

Role of Food Products in Child Health and Nutrition

Food products play a crucial role in ensuring optimal health and nutrition for children. Adequate nutrition during childhood is essential for growth, development, and overall well-being. The quality of the diet in early life can have long-lasting effects on cognitive function, immune system development, physical growth, and the ability to fight off infections. This is particularly important for children in their formative years, as proper nutrition supports their rapidly developing bodies and minds[17-18].

The role of food products in child health and nutrition can be broken down into several key areas:

Providing Essential Nutrients

Children need a balanced diet that includes essential nutrients for proper growth and development. Key nutrients that are vital during childhood include:

- **Proteins:** Proteins are essential for the growth and repair of tissues, the production of enzymes and hormones, and immune function. Food sources rich in protein include meat, poultry, fish, eggs, legumes, and dairy products.
- **Carbohydrates:** Carbohydrates are the body's primary source of energy. Healthy carbohydrates, such as whole grains, fruits, and vegetables, provide the energy needed for physical activity and brain function.
- **Fats:** Healthy fats are crucial for brain development, the absorption of fat-soluble vitamins (A, D, E, and K), and overall growth. Sources include avocados, nuts, seeds, and fish oils.
- **Vitamins and Minerals:** Micronutrients such as vitamins (A, D, C, and the B-complex group) and minerals (iron, calcium, magnesium, zinc) are vital for maintaining various body functions. For example, calcium and vitamin D are important for bone health, while iron is essential for oxygen transport in the blood.
- **Fiber:** Dietary fiber, found in whole grains, fruits, and vegetables, promotes healthy digestion and helps prevent constipation, which is a common concern among children.

Supporting Immune Function

A balanced diet supports the development and functioning of the immune system, helping children fight off infections and illnesses. Key nutrients involved in immune health include:

- **Vitamin A:** This vitamin is crucial for maintaining the health of the skin and mucous membranes, which act as barriers to infections. Vitamin A also supports the production of white blood cells.
- **Vitamin C:** Vitamin C enhances the production and function of white blood cells and acts as an antioxidant, protecting cells from damage caused by free radicals.

- **Zinc:** Zinc is essential for immune cell production and proper immune responses. A deficiency can leads to increased susceptibility to infections.
- **Iron:** Iron deficiency can lead to weakened immune function, making children more vulnerable to illnesses.

Promoting Growth and Development

Adequate nutrition is essential for ensuring that children grow at the proper rate. Malnutrition or undernutrition can result in stunted growth, developmental delays, and other long-term health problems. Key aspects of growth and development influenced by food products include:

- **Physical Growth:** Nutrients like protein, vitamins, and minerals are critical for bone development, muscle growth, and tissue repair. For instance, calcium and vitamin D are crucial for developing strong bones and teeth.
- **Cognitive Development:** The brain undergoes rapid growth and development in the early years of life, and nutrition plays a key role in cognitive function. Omega-3 fatty acids (found in fish and certain oils) are important for brain development, while iron and iodine are essential for cognitive function.
- **Height and Weight Gain:** A well-balanced diet ensures that children grow at the right pace. Malnutrition or deficiencies in key nutrients can lead to stunting (low height for age) and underweight status, which can have lasting effects on a child's health.

Preventing Malnutrition and Micronutrient Deficiencies

Malnutrition, which includes both undernutrition and overnutrition, is a major global health concern. Micronutrient deficiencies (such as iron, vitamin A, and iodine) can impair children's health, causing issues like developmental delays, poor academic performance, and weakened immunity. Food products can play a significant role in preventing these deficiencies by providing the necessary nutrients.

- **Iron Deficiency:** Iron deficiency is one of the most common nutritional deficiencies in children and can lead to anemia. Iron-rich foods such as lean meats, spinach, lentils, and fortified cereals can prevent iron deficiency.
- **Vitamin A Deficiency:** Vitamin A deficiency can cause vision problems, especially night blindness, and increase susceptibility to infections. Sources of vitamin A include liver, eggs, dairy products, and orange-colored fruits and vegetables like carrots and sweet potatoes.

- **Iodine Deficiency:** Iodine is essential for thyroid function and cognitive development. Iodized salt is a simple, effective way to prevent iodine deficiency, especially in regions where iodine deficiency is prevalent.

Maintaining a Healthy Gut

The gut microbiome plays a critical role in a child's overall health, including digestion, immunity, and mental health. A healthy gut microbiome is supported by a diet rich in fiber, prebiotics, and probiotics.

- **Fiber-Rich Foods:** Foods like whole grains, fruits, and vegetables support gut health by promoting regular bowel movements and feeding beneficial gut bacteria.
- **Probiotics:** Fermented foods such as yogurt, kefir, and kimchi provide beneficial bacteria (probiotics) that support gut health and may boost immune function.
- **Hydration:** Proper hydration is also essential for maintaining healthy digestion and supporting overall health. Water, milk, and fresh fruit juices are good sources of hydration for children.

Managing Chronic Diseases and Preventing Obesity

Nutrition plays an important role in preventing and managing chronic diseases such as obesity, diabetes, and cardiovascular diseases. A healthy, balanced diet can help children maintain a healthy weight and reduce their risk of developing these diseases later in life.

- **Obesity Prevention:** High consumption of sugary, processed foods and sedentary behavior contribute to childhood obesity. A diet rich in whole foods (vegetables, fruits, lean proteins, and whole grains) can help prevent obesity by providing essential nutrients while avoiding excess calories.
- **Managing Diabetes Risk:** A balanced diet with controlled carbohydrate intake can help manage and prevent the development of type 2 diabetes in children, particularly in those at higher risk.

Role of Fortified Food Products

Fortified food products can be particularly helpful in areas where certain micronutrient deficiencies are common. Fortification involves adding nutrients to food that are not naturally present or are present in insufficient amounts. Some examples include:

- **Iron-Fortified Cereals:** Iron-fortified cereals can help address the widespread problem of iron deficiency in children.
- **Vitamin D-Fortified Milk:** Vitamin D is essential for bone health, and milk fortified with vitamin D is an important dietary source.

- **Iodized Salt:** The addition of iodine to salt has been a successful global strategy to prevent iodine deficiency and its associated problems, such as intellectual impairments and goiter.

Integrating Anthelmintic Drugs into Food Products

The integration of anthelmintic drugs into food products for children represents a novel approach to addressing the high prevalence of parasitic infections in areas with limited access to healthcare and medicines. This method seeks to ensure that children in endemic regions receive consistent and effective treatment for parasitic infections without the need for individual prescriptions or visits to healthcare facilities. The concept of incorporating anthelmintic drugs into food products could provide a simple, accessible, and cost-effective solution for combating parasitic diseases, especially among children who are particularly vulnerable to the negative health effects of helminth infections[19].

Rationale for Integrating Anthelmintic Drugs into Food Products

- **Wide Reach:** One of the main benefits of incorporating anthelmintic drugs into food products is the ability to reach a large portion of the population, particularly children. In regions with high rates of parasitic infections and limited access to healthcare, food-based interventions can effectively deliver treatment to large numbers of children without the need for complex healthcare infrastructure.
- **Targeting Vulnerable Populations:** Children in rural or impoverished areas may have limited access to healthcare, leading to untreated parasitic infections that can cause malnutrition, stunted growth, and cognitive impairments. Food products that are already part of a child's daily diet can provide an easy and consistent means of delivering treatment.
- **Improved Compliance:** Many children, particularly in low-resource settings, may not take medicine regularly or as prescribed due to fear, taste, or a lack of understanding. By integrating anthelmintic drugs into foods that are already familiar and appealing, adherence to treatment becomes less of an issue, improving the effectiveness of deworming programs.

Types of Food Products for Integration

Food products can vary in form and function depending on the target population's preferences, local diets, and the specific anthelmintic drugs being used. Examples include:

- **Fortified Staple Foods:** Staple foods such as flour, rice, or maize can be fortified with anthelmintic drugs. In many low-income countries, these foods are consumed regularly, and fortifying them with anthelmintics ensures widespread distribution with minimal disruption to children's regular eating habits.

- **Ready-to-Use Therapeutic Foods (RUTFs):** These are nutrient-dense, therapeutic foods typically used in the treatment of malnutrition. By integrating anthelmintic drugs into RUTFs, children can receive both nutritional support and deworming treatment simultaneously.
- **Biscuits or Cookies:** These are easy-to-consume, child-friendly products that can be fortified with anthelmintic drugs. The familiarity and taste appeal to children, ensuring better adherence to treatment[20].
- **Fortified Milk and Dairy Products:** Dairy products, which are commonly consumed by children, can be an effective vehicle for delivering anthelmintics. Fortified milk and yogurt products could provide regular doses of anthelmintics.
- **Juices or Liquid Supplements:** In some regions, fortified juices or liquid nutritional supplements could provide a vehicle for the incorporation of anthelmintic drugs, especially for children who may have difficulty swallowing tablets or pills.

Benefits of Integrating Anthelmintic Drugs into Food Products

- **Enhanced Access to Treatment:** The primary benefit of this integration is increased access to anthelmintic drugs. Children who may otherwise not receive the treatment due to logistical challenges or lack of healthcare infrastructure can still be reached through regular food consumption.
- **Prevention of Recurrent Infections:** The regular consumption of food products containing anthelmintic drugs can help prevent reinfection, ensuring that children in endemic areas receive ongoing protection against parasitic infections.
- **Improved Health Outcomes:** Deworming is associated with a number of positive health outcomes for children, including improved growth, better cognitive function, reduced anemia, and a stronger immune system. Incorporating anthelmintics into food products ensures that children can benefit from these effects without delay or gaps in treatment.
- **Cost-Effectiveness:** Mass treatment programs that integrate anthelmintics into widely consumed food products could be more cost-effective than providing individualized treatment through traditional healthcare methods. The process of fortifying food products can be streamlined and scalable, allowing it to reach a larger population at a lower cost.

Conclusion:

Anthelmintic drugs play a vital role in improving children's health by effectively treating parasitic worm infections, which are common in many parts of the world, especially in low-income and rural areas. These infections, caused by helminths such as roundworms, hookworms, and whipworms, can lead to significant health issues, including malnutrition, stunted growth, cognitive impairments, anemia, and weakened immune systems.

Key Contributions to Children's Health:

1. **Improved Growth and Development:** Parasitic infections can hinder a child's physical growth and cognitive development. By eliminating these infections, anthelmintic drugs help children achieve their full growth potential, improving both physical stature and mental performance[21].
2. **Enhanced Nutritional Status:** Worm infections often cause malnutrition due to the parasites consuming nutrients from the host, leading to deficiencies. Deworming improves the absorption of nutrients and contributes to better overall nutrition, reducing the risk of stunting and micronutrient deficiencies.
3. **Boosted Immune Function:** Parasitic infections can weaken a child's immune system, making them more susceptible to other illnesses. Anthelmintics help restore immune function, enabling the child's body to better fight off infections and illnesses.
4. **Reduction in Anemia:** Many parasitic worms, particularly hookworms, lead to blood loss, resulting in anemia. Anthelmintic treatment helps reduce parasitic load, thereby improving hemoglobin levels and preventing anemia, which is critical for a child's energy levels and overall health.
5. **Improved School Performance:** Deworming helps improve concentration, cognitive function, and academic performance in children by reducing the physical and mental burden of parasitic infections. Healthy, dewormed children are more likely to attend school regularly and perform better academically.

Integrating Anthelmintics for Broader Impact:

Incorporating anthelmintic drugs into food products for children provides a cost-effective and accessible method to deliver deworming treatment, especially in regions where healthcare access is limited. By using food as a delivery vehicle, children can receive consistent treatment without the need for regular medical visits, improving compliance and reducing the burden of parasitic infections in affected communities.

In conclusion, anthelmintic drugs are crucial for improving children's health by tackling parasitic infections that negatively impact growth, nutrition, and overall development. Their role extends beyond treating infections, contributing to better health outcomes and enhancing children's quality of life.

References:

1. Chifunda, K., & Kelly, P. (2019). Parasitic infections of the gut in children. *Paediatrics and International Child Health, 39*(1), 65–72.
2. Mallewa, M., & Wilmshurst, J. M. (2014). Overview of the effect and epidemiology of parasitic central nervous system infections in African children. *Seminars in Pediatric Neurology, 21*(1), 19–25. WB Saunders.
3. Yadav, P., & Singh, R. (2011). A review on anthelmintic drugs and their future scope. *International Journal of Pharmacy and Pharmaceutical Sciences, 3*(3), 17–21.
4. Panic, G., Duthaler, U., Speich, B., & Keiser, J. (2014). Repurposing drugs for the treatment and control of helminth infections. *International Journal for Parasitology: Drugs and Drug Resistance, 4*(3), 185–200.
5. Stephenson, L. S. (2001). Optimising the benefits of anthelmintic treatment in children. *Paediatric Drugs, 3*, 495–508.
6. Hotez, P. J., Strych, U., Lustigman, S., & Bottazzi, M. E. (2016). Human anthelminthic vaccines: Rationale and challenges. *Vaccine, 34*(30), 3549–3555.
7. Harhay, M. O., Horton, J., & Olliaro, P. L. (2010). Epidemiology and control of human gastrointestinal parasites in children. *Expert Review of Anti-Infective Therapy, 8*(2), 219–234.
8. Jayawardene, K. D., Palombo, E. A., & Boag, P. R. (2021). Natural products are a promising source for anthelmintic drug discovery. *Biomolecules, 11*(10), 1457.
9. Sheth, U. K. (1975). Mechanisms of anthelmintic action. *Progress in Drug Research/Fortschritte der Arzneimittelforschung/Progrès des Recherches Pharmaceutiques: Tropical Diseases II/Tropische Krankheiten II/Maladies Tropicales II*, 147–157.
10. Rew, R. S. (1978). Mode of action of common anthelmintics. *Journal of Veterinary Pharmacology and Therapeutics, 1*(3), 183–197.
11. Fissiha, W., & Kinde, M. Z. (2021). Anthelmintic resistance and its mechanism: A review. *Infection and Drug Resistance, 14*, 5403–5410.

12. Brown, H. W. (1960). The actions and uses of anthelmintics. *Clinical Pharmacology & Therapeutics, 1*(1), 87–103.
13. Stephenson, L. S. (2001). Optimising the benefits of anthelmintic treatment in children. *Paediatric Drugs, 3*, 495–508.
14. Porto, I. (2003). Antiparasitic drugs and lactation: Focus on anthelmintics, scabicides, and pediculicides. *Journal of Human Lactation, 19*(4), 421–425.
15. Mehraj, V., Hatcher, J., Akhtar, S., Rafique, G., & Beg, M. A. (2008). Prevalence and factors associated with intestinal parasitic infection among children in an urban slum of Karachi. *PLOS ONE, 3*(11), e3680.
16. Ibrakhimova, H. R., & Oblokulov, A. R. (2020). Pathogenetic bases and prevalence of parasitic infections in children: Literature review. *The American Journal of Medical Sciences and Pharmaceutical Research, 2*(10), 87–95.
17. Caballero, B. (2002). Global patterns of child health: The role of nutrition. *Annals of Nutrition and Metabolism, 46*(Suppl. 1), 3–7.
18. Shamah, T., & Villalpando, S. (2006). The role of enriched foods in infant and child nutrition. *British Journal of Nutrition, 96*(S1), S73–S77.
19. Nixon, S. A., Welz, C., Woods, D. J., Costa-Junior, L., Zamanian, M., & Martin, R. J. (2020). Where are all the anthelmintics? Challenges and opportunities on the path to new anthelmintics. *International Journal for Parasitology: Drugs and Drug Resistance, 14*, 8–16.
20. Tan, P. Y., Loganathan, R., Teng, K. T., Lee, S. C., Johari, S. N., Selvaduray, K. R., Ngui, R., & Lim, Y. A. (2023). Red palm olein-enriched biscuit supplementation lowers *Ascaris lumbricoides* reinfection at 6-month after anthelmintic treatment among schoolchildren with vitamin A deficiency (VAD). *Acta Tropica, 240*, 106860.
21. Dror, D. K., & Allen, L. H. (2014). Dairy product intake in children and adolescents in developed countries: Trends, nutritional contribution, and a review of association with health outcomes. *Nutrition Reviews, 72*(2), 68–81.

THE MICROBE-FIGHTING MAGIC OF HERBS: A JOURNEY INTO HERBAL ALCHEMY

Rajesh A. Maheshwari*, Ashim Kumar Sen, Dhanya B. Sen and Rahul Trivedi

Department of Pharmacy,

Sumandeep Vidyapeeth Deemed to be University, Piparia, Vadodara-391760, Gujarat

*Corresponding author E-mail: rajpharma2007@gmail.com

Abstract:

The fusion of ancient herbal practices with modern scientific research unveils the potential of plant-based therapies in combating microbial infections. "Herbal Alchemy: Unraveling the Antimicrobial Properties of Plants" explores the antimicrobial capabilities of various plants historically used in traditional medicine, such as garlic, neem, eucalyptus, and ginger. These plants have long provided remedies for infections, and contemporary research is increasingly validating their effectiveness through the identification of bioactive compounds. This chapter bridges the gap between ancient wisdom and modern science, revealing how phytochemicals, essential oils, and other compounds play crucial roles in inhibiting harmful microbes. With growing concerns over antimicrobial resistance (AMR) due to overuse of synthetic antibiotics, the search for sustainable alternatives is critical. Plant-based remedies offer a promising solution, as they tend to have broader action spectra and fewer side effects. Research highlights the antimicrobial potential of plants like garlic, betel, cinnamon, and bitter melon, showing effectiveness against a range of pathogens while avoiding the rapid resistance development associated with conventional antibiotics. The study also underscores the significant role of these natural remedies in addressing the environmental and health challenges posed by AMR. Ultimately, this chapter advocates for further exploration of plant-based alternatives, emphasizing their role in future healthcare strategies, especially as complementary or replacement therapies for microbial infections.

Keywords: Herbal Alchemy, Antimicrobial Properties, Garlic, Betel, Cinnamon, Bitter Melon

Introduction:

In the expansive world of nature's healing resources, the union of ancient traditions and modern science reveals a compelling narrative of untapped therapeutic potential. *Herbal Alchemy: Unraveling the Antimicrobial Properties of Plants* invites us on a captivating journey that transcends time and cultures, where ancient knowledge converges with contemporary research to uncover the remarkable antimicrobial properties of various plant species. For centuries, traditional herbal medicine has been at the heart of healthcare systems worldwide, offering remedies for a broad range of ailments, including infectious diseases. From the use of garlic and ginger to the healing properties of neem and eucalyptus, different cultures have harnessed the healing power of plants, often passing down these practices through generations. In recent years, this ancient wisdom has garnered renewed attention from the scientific community, as modern researchers increasingly validate the antimicrobial potential found within plant-based remedies. With advancements in technology and a deeper understanding of plant biology, the antimicrobial properties of herbs are being systematically explored and confirmed. This synergy between tradition and modern science holds exciting promise for the future of healthcare, potentially offering new, natural solutions for combating infections and other health concerns. The book delves into this fascinating intersection, revealing how the age-old practice of herbal medicine is not only rooted in history but is also being rediscovered as a valuable tool in the fight against microbial threats.[1-3]

This chapter aims to bridge the gap between the ancient practice of herbalism and modern scientific understanding, offering a thorough exploration of the crucial roles plants play in combating microbial threats. With a rich diversity of phytochemicals, essential oils, and bioactive compounds, plants have long been recognized for their medicinal properties. These plant-based elements are not only fascinating from a botanical perspective but also hold immense potential for the development of new antimicrobial agents. As we embark on this exploration, we delve deeper into the complexities of herbal alchemy, examining the molecular mechanisms that enable certain plants to effectively target and neutralize harmful microbes.

Herbal remedies have been used for centuries across cultures, with many plants providing natural defense against pathogens. In modern times, these time-tested remedies are being scrutinized with cutting-edge scientific tools, allowing researchers to identify specific bioactive compounds responsible for antimicrobial activity. This intersection of traditional knowledge and contemporary research opens up exciting possibilities for developing novel treatments that are both effective and sustainable. Through a lens that integrates cultural wisdom with scientific inquiry, this chapter aims to highlight the dynamic relationship between plants and microbes. By understanding how plants have evolved to protect themselves from microbial threats, we can harness their inherent antimicrobial properties to develop alternatives to synthetic antibiotics. In light of the growing global challenge of antimicrobial resistance, nature-inspired solutions could offer a promising path forward, providing safer and more sustainable approaches to combating infections. This chapter sheds light on the potential of plants as key players in the fight against antimicrobial resistance, paving the way for future research and innovation.[4]

Drawbacks of standard microbial infection therapy

Conventional therapies for treating microbial infections, primarily relying on antibiotics and synthetic drugs, have long been the cornerstone of modern medicine. However, these treatments come with a range of limitations and risks that are becoming increasingly apparent. One of the most significant concerns is the growing problem of antimicrobial resistance (AMR), where microorganisms evolve to become resistant to the drugs designed to kill them. This phenomenon is a direct result of the overuse and misuse of antibiotics, which accelerate the development of resistant strains. As a result, infections that were once easily treatable with common antibiotics are becoming harder, and in some cases, impossible to manage. Another limitation of conventional therapy is the narrow spectrum of action exhibited by many synthetic antimicrobial agents. These drugs are often effective only against specific types of bacteria, viruses, or fungi, necessitating a precise diagnosis before treatment. Misdiagnosis or incorrect prescription can lead to ineffective treatment or even the development of resistance. Furthermore, conventional antibiotics can disrupt the natural balance of microorganisms in the body, particularly in the gut, leading to side effects such as gastrointestinal disturbances, yeast infections, or even secondary infections like Clostridium difficile. Additionally, many pharmaceutical drugs come with potential side effects, ranging from mild symptoms like nausea and dizziness to more severe reactions such as liver damage, kidney toxicity, and allergic reactions. These risks are particularly concerning in vulnerable populations such as the elderly, children, and individuals with compromised immune systems. Long-term use of antibiotics can also result in the development of "superbugs, " resistant strains of bacteria that are no longer susceptible to common treatments. Lastly, the environmental impact of conventional antimicrobial therapy is a growing issue. The disposal of unused medications and the release of antibiotics into wastewater systems can contribute to the development of resistant microbes in the environment, further complicating the global challenge of managing infectious diseases. As a result, there is a growing need for alternative therapies, such as plant-based remedies, to complement or replace conventional antibiotics and offer a sustainable solution to the treatment of microbial infections.[5-7]

Botanical interventions for microbial infections

Herbs with antimicrobial properties offer several advantages as alternative or complementary treatments for microbial infections. One of the key benefits is their natural origin, which often leads to fewer side effects compared to synthetic antibiotics. Many herbs contain compounds that are capable of targeting a broad range of pathogens, including bacteria, fungi, and viruses, without the risk of resistance developing as rapidly as with conventional antibiotics. Additionally, herbs often possess antioxidant, anti-inflammatory, and immune-boosting properties, which can help enhance the body's overall ability to fight infections. Furthermore, the availability and affordability of some herbs make them an accessible option, especially in regions with limited access to pharmaceutical treatments. Their use also encourages a more holistic approach to health and healing.

Garlic

This study examined the antimicrobial effects of essential oil extracts from three onion varieties—green, yellow, and red—along with garlic. These extracts were tested at varying concentrations (50, 100, 200, 300, and 500 ml/l) against a range of microorganisms, including the bacteria Staphylococcus aureus and *Salmonella Enteritidis*, as well as the fungi *Aspergillus niger, Penicillium cyclopium*, and *Fusarium oxysporum*. The results revealed that garlic exhibited the strongest antimicrobial activity, effectively inhibiting the growth of most pathogens at all tested concentrations. In contrast, green onion extracts showed the weakest inhibitory effects, although they still demonstrated notable antibacterial activity. Increasing the concentration of onion extracts to 200, 300, and 500 ml/l resulted in enhanced antimicrobial effects, with higher concentrations proving particularly potent against certain microorganisms. Notably, both red onion and garlic extracts were highly effective against *S. Enteritidis*, while S. aureus showed lower sensitivity. Among the fungi tested, *F. oxysporum* displayed the least response to the extracts. Overall, the study suggests that essential oil extracts from onions and garlic, particularly at higher concentrations, could serve as promising natural antimicrobial agents for use in food products, offering an alternative to synthetic preservatives.[8]

The study investigated the fungitoxic effects of various medicinal plants from different plant families against *Rhizoctonia solani*, the pathogen responsible for rice sheath blight, in vitro. Among the extracts tested, zimmu leaf extract, a hybrid of *Allium cepa* (onion) and *Allium sativum* (garlic), demonstrated the most potent antifungal activity, forming a notable 12-mm inhibition zone against *R. solani*. This extract also showed effectiveness against other significant fungal and bacterial pathogens that affect crops. The antimicrobial compound in the zimmu extract was soluble in methanol and displayed absorption peaks at 210 and 230 nm, which is characteristic of phenolic compounds. Thin-layer chromatography (TLC) analysis revealed two prominent blue spots at retention factors (Rf) of 0.65 and 0.90, suggesting the presence of active compounds. Preparative TLC further confirmed that these compounds effectively inhibited *R. solani*. The study concluded that zimmu leaf extract contains bioactive compounds with considerable antifungal potential, making it a promising candidate for controlling rice sheath blight and other plant diseases. Moreover, the identification of these bioactive compounds paves the way for further research into their antimicrobial properties, with the potential for developing natural, plant-based alternatives to synthetic pesticides in agricultural disease management. This underscores the value of medicinal plants in providing sustainable solutions for managing plant diseases.[9]

Betel or Sireh

The ethanol extract from *Piper betel* leaves, known as Paan, has long been appreciated in Indian traditional medicine for its antioxidant and antibacterial properties. This study aimed to evaluate the antimicrobial potential of this extract. The results demonstrated significant free radical scavenging activity, indicating strong antioxidant properties, as well as notable antibacterial effects against a variety of human pathogenic bacteria, including both gram-positive and gram-negative strains. The antimicrobial activity was found to be concentration-dependent, with Minimum Inhibitory Concentrations (MICs) ranging from 25 µg to 40 µg across different bacterial strains. Additionally, time-kill kinetics showed a decline in bacterial growth six hours after applying the ethanol extract, suggesting its persistent antimicrobial action. These findings confirm the traditional use of *Piper betel* leaf extract, verifying its powerful antibacterial effects, particularly against harmful pathogens. The study also explored the use of a standardized ethanol extract of *P. betel* in creating a mouthwash formulation. The active compound, hydroxychavicol, was identified during the extraction process, and two variants, Actifold 30 and Actifold 60, were evaluated for their hydroxychavicol content. Antimicrobial tests revealed that these extracts effectively inhibited bacterial growth at low MICs. Notably, hydroxychavicol in Actifold showed a significantly lower MIC compared to commercial mouthwash ingredients, indicating its superior antimicrobial properties. The mouthwash formulation using Actifold demonstrated an MBC half that of a commercial product, and a mouthwash with hydroxychavicol alone matched the MBC of the commercial version. Actifold 30x, a more concentrated extract, showed strong efficacy at 2.5 times its MBC value in low-alcohol formulations. Moreover, *Aspergillus niger* exhibited the highest inhibition in the presence of the extract, further confirming its broad antimicrobial activity. In conclusion, this study highlights the antimicrobial potential of *Piper betel* ethanol extract, particularly hydroxychavicol, as a natural alternative to synthetic antibiotics. These findings suggest that *P. betel* extracts could be an effective component in the development of mouthwashes and other antimicrobial products, providing a traditional and potent remedy for combating pathogenic bacteria.[10, 11]

Cinnamon

The study aimed to assess the antimicrobial properties of an aqueous extract derived from the stem bark of *Cinnamomum verum*, commonly known as cinnamon, against a variety of bacterial strains, including normal flora, nosocomial pathogens, and foodborne bacteria. The extraction process yielded 2.5% of the dried plant material. The results showed that *Cinnamomum verum* demonstrated inhibitory effects on multiple bacterial strains, such as *Escherichia coli*, *Staphylococcus epidermidis*, and *Klebsiella pneumoniae*, as indicated by an agar diffusion test. The minimum bactericidal concentrations (MBCs) and minimum inhibitory concentrations (MICs) varied depending on the bacterial strain, with MICs ranging from low to high concentrations. Notably, the aqueous extract of *C. verum* stem bark exhibited significant inhibition at lower concentrations against *S. epidermidis*, *K. pneumoniae*, and *E. coli*. These findings emphasize the potential of *Cinnamomum verum* as a promising natural antimicrobial agent, offering valuable insight into its use for combating harmful pathogens. In addition to this, the study also investigated the antimicrobial effects of four essential oils—turmeric oil, leech lime oil, cinnamon oil, and lemongrass oil—against *Streptococcus iniae*, the pathogen responsible for streptococcosis in fish. Among the essential oils tested, cinnamon oil exhibited the most robust antimicrobial activity, demonstrating the lowest MIC against *S. iniae*. The gas chromatography-mass spectrometry (GC-MS) analysis of cinnamon oil revealed the major chemical components, including cinnamaldehyde, limonene, cinnamyl acetate, linalool, and α-terpineol. Of these compounds, only cinnamaldehyde exhibited antimicrobial activity against the fish pathogen, with a remarkable MIC value. Furthermore, in vivo trials conducted on tilapia fish indicated that cinnamon oil, when combined with oxytetracycline, effectively protected the fish from *S. iniae* infection, preventing any mortality. This outcome suggests that cinnamon oil, due to its potent antimicrobial properties, could be considered as a natural and safer alternative to antibiotics in treating fish streptococcosis. The use of cinnamon oil could potentially reduce the reliance on synthetic antibiotics, offering an environmentally friendly approach to managing fish diseases. In conclusion, the study highlights the antimicrobial effectiveness of both *Cinnamomum verum* aqueous extract and cinnamon essential oil, showing their significant potential in combating bacterial pathogens in both human and aquaculture applications. These findings support the use of natural plant-derived products as viable alternatives to conventional antimicrobial agents.[12, 13]

Bitter Melon

This study analyzed the essential oil extracted from bitter melon seeds. Gas chromatography-mass spectrometry (GC-MS) identified 25 components that made up 90.9% of the oil. Major constituents included trans-nerolidol, apiole, cis-dihydrocarveol, and germacrene D. The oil demonstrated strong antibacterial and antifungal effects against *Staphylococcus aureus*, with minimum inhibitory concentrations (MICs) below 500 µg/ml, indicating high sensitivity of the bacteria to the oil. Additionally, the study examined the antimicrobial and antioxidant properties of bitter melon fruit and seed ethanol extracts sourced from Turkey. These extracts displayed significant antimicrobial activity against a variety of bacteria, yeast, and fish pathogens. Among the extracts, the unripe fruit extract showed the highest antimicrobial effectiveness, while the ripe fruit extract exhibited the greatest antioxidant capacity. The results suggest that both ripe and unripe fruit extracts possess strong antibacterial and antioxidant properties, positioning them as potential natural preservatives for food and other applications.

The study emphasizes the potential of bitter melon extracts, particularly from both ripe and unripe fruits, as effective natural preservatives due to their powerful antimicrobial and antioxidant properties. This suggests the possibility of using these extracts to enhance food safety and quality, providing a natural alternative to synthetic preservatives.[14, 15]

Barberry

This study examined the antidermatophytic properties of different extracts from *Berberis vulgaris* (commonly known as barberry), with a focus on berberine, against dermatophytes like *Microsporum gypseum*, *Trichophyton rubrum*, *Trichophyton mentagrophytes*, and *Microsporum canis* in vitro. The minimum inhibitory concentration

(MIC) was measured using the CLSI broth macrodilution method and the disk diffusion test. The study also evaluated the antileishmanial and cytotoxic effects of *B. vulgaris* and berberine on *Leishmania major* and *Leishmania tropica* promastigotes using the colorimetric MTT assay. The results showed strong antidermatophytic activity, with MIC values ranging from 0.125 to more than 4 mg/mL for various *B. vulgaris* extracts, especially berberine. Both *B. vulgaris* extracts and berberine effectively suppressed the growth of *L. major* and *L. tropica* promastigotes in a dose-dependent manner, with IC50 values between 2.1 and 26.6 μg/mL. Berberine showed greater cytotoxicity against mouse macrophages compared to *B. vulgaris*, with CC50 values ranging from 27.3 to 362.6 μg/mL. These findings suggest that *B. vulgaris* extracts, particularly berberine, hold significant potential for developing new treatments for dermatophytic infections and leishmaniasis. However, further studies, including clinical trials on humans and animals, are necessary to confirm the effectiveness and safety of these extracts for medical use.[16]

Bael or Bili

This study investigated the medicinal potential of *Aegle marmelos* (Bael) in traditional medicine, particularly its antimicrobial properties. Phytochemical analysis of methanolic and aqueous leaf extracts from eighteen *A. marmelos* varieties revealed that the Pant Aparna variety contained the highest levels of phenols, flavonoids, and alkaloids. Antibacterial tests indicated that the methanolic extract effectively inhibited *Staphylococcus aureus*, while the aqueous extract was potent against *Staphylococcus epidermidis*. The aqueous:ethanol extract was also effective against *Enterobacter aerogenes*, *Klebsiella pneumoniae*, and *S. epidermidis*. The Minimum Inhibitory Concentrations (MICs) for the aqueous and methanolic extracts ranged from 10 mg/mL to 40 mg/mL, while the aqueous:ethanol extract showed MICs from 40 mg/mL to 160 mg/mL. Gas Chromatography-Mass Spectrometry (GC-MS) analysis revealed several bioactive compounds, suggesting their contribution to the antimicrobial activity. In addition, the study explored the antimicrobial properties of methanolic extracts from different parts of *A. marmelos*, including leaves and flowers. These extracts exhibited significant inhibitory effects against both gram-positive and gram-negative bacteria, such as *Salmonella typhi*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Proteus mirabilis*, and *Staphylococcus aureus*. The results confirmed that methanolic extracts of *A. marmelos* possess potent antibacterial properties, highlighting their potential for treating infections caused by antibiotic-resistant microorganisms. This reinforces the traditional use of Bael as a medicinal herb, offering a promising natural alternative to combat microbial resistance.[17, 18]

Conclusion:

In conclusion, the fusion of ancient herbal knowledge with modern scientific advancements presents a promising frontier in the fight against microbial infections. The exploration of plant-based remedies, such as garlic, cinnamon, and bitter melon, reveals their potent antimicrobial properties, which are being validated through contemporary research. Unlike synthetic antibiotics, many of these herbal solutions show a broader spectrum of action, fewer side effects, and reduced risk of resistance. As the global threat of antimicrobial resistance grows, natural plant-derived compounds may provide safer, sustainable alternatives. The continued study of these medicinal plants offers a hopeful path toward developing innovative treatments for infections, benefiting both human health and the environment. By integrating traditional wisdom with modern science, we may unlock the full potential of plants as powerful allies in combating microbial challenges.

References:

1. Clark, A. M. (1996). Natural products as a resource for new drugs. *Pharmaceutical Research, 13*, 1996.
2. Tsuchiya, H., Sato, M., Miyazaki, T., Fujiwara, S., Tanigaki, S., Ohyama, M., et al. (1996). Comparative study on the antibacterial activity of phytochemical flavanones against methicillin-resistant *Staphylococcus aureus*. *Journal of Ethnopharmacology, 50*, 27–34.
3. Cowan, M. M. (1999). Plant products as antimicrobial agents. *Clinical Microbiology Reviews, 12*(4), 564–582.
4. Hamburger, H., & Hostettmann, K. (1991). The link between phytochemistry and medicine. *Phytochemistry, 30*, 3864–3874.
5. Alaoui Mdarhri, H., Benmessaoud, R., Yacoubi, H., Seffar, L., Guennouni Assimi, H., & Hamam, M., et al. (2022). Alternative therapeutic approaches to conventional antibiotics: Advantages, limitations, and potential application in medicine. *Antibiotics, 11*(12), 1826.
6. Tse, B. N., Adalja, A. A., Houchens, C., Larsen, J., Inglesby, T. V., & Hatchett, R. (2017). Challenges and opportunities of nontraditional approaches to treating bacterial infections. *Clinical Infectious Diseases, 65*(3), 495–500.
7. Batoni, G., Maisetta, G., Lisa Brancatisano, F., Esin, S., & Campa, M. (2011). Use of antimicrobial peptides against microbial biofilms: Advantages and limits. *Current Medicinal Chemistry, 18*(2), 256–279.

8. Benkeblia, N. (2004). Antimicrobial activity of essential oil extracts of various onions (*Allium cepa*) and garlic (*Allium sativum*). *LWT-Food Science and Technology, 37*(2), 263–268.
9. Satya, V. K., Radhajeyalakshmi, R., Kavitha, K., Paranidharan, V., Bhaskaran, R., & Velazhahan, R. (2005). *In vitro* antimicrobial activity of zimmu (*Allium sativum L. × Allium cepa L.*) leaf extract. *Archives of Phytopathology and Plant Protection, 38*(3), 185–192.
10. Singgih, M. A., Damayanti, S. O., & Pandjaitan, N. A. (2014). Antimicrobial activity of standardized *Piper betel* extract and its mouthwash preparation. *International Journal of Pharmaceutical Sciences, 6*(7), 243–246.
11. Datta, A., Ghoshdastidar, S., & Singh, M. (2011). Antimicrobial property of *Piper betel* leaf against clinical isolates of bacteria. *International Journal of Pharma Sciences and Research, 2*(3), 104–109.
12. Rattanachaikunsopon, P., & Phumkhachorn, P. (2010). Potential of cinnamon (*Cinnamomum verum*) oil to control *Streptococcus iniae* infection in tilapia (*Oreochromis niloticus*). *Fisheries Science, 76*, 287–293.
13. Puangpronpitag, D., & Sittiwet, C. (2009). Antimicrobial properties of *Cinnamomum verum* aqueous extract. *Asian Journal of Biological Sciences, 2*(2), 49–53.
14. Ozusaglam, M. A., & Karakoca, K. (2013). Antimicrobial and antioxidant activities of *Momordica charantia* from Turkey. *African Journal of Biotechnology, 12*(13), 1548–1558.
15. Braca, A., Siciliano, T., D'Arrigo, M., & Germanò, M. P. (2008). Chemical composition and antimicrobial activity of *Momordica charantia* seed essential oil. *Fitoterapia, 79*(2), 123–125.
16. Mahmoudvand, H., Ayatollahi Mousavi, S. A., Sepahvand, A., Sharififar, F., Ezatpour, B., Gorohi, F., et al. (2014). Antifungal, antileishmanial, and cytotoxicity activities of various extracts of *Berberis vulgaris* (Berberidaceae) and its active principle berberine. *International Scholarly Research Notices, 2014*, 602436.
17. Suresh, K., Senthilkumar, P. K., & Karthikeyan, B. (2009). Antimicrobial activity of *Aegle marmelos* against clinical pathogens. *Journal of Phytology, 1*(5), 323–327.
18. Mujeeb, F., Bajpai, P., & Pathak, N. (2014). Phytochemical evaluation, antimicrobial activity, and determination of bioactive components from leaves of *Aegle marmelos*. *BioMed Research International, 2014*, 497606.

ETHNOMEDICINAL USES OF CURCUMIN: THE SPICE OF OUR DAILY DIET

Jayita Roy[1], Tuhar Mukherjee[2] and Sutapa Datta*[3]

[1]Biotechnology Research and Innovation Council,

National Institute of Biomedical Genomics, Kalyani, 741251, West Bengal, India

[2] Mahant Avaidyanath Government Degree College,

Jungle Kaudia, Gorakhpur, 273007, Uttar Pradesh, India

[3]Bethune College, 181, Bidhan Sarani, Kolkata700006, West Bengal, India

*Corresponding author E-mail: dattasutapa@gmail.com

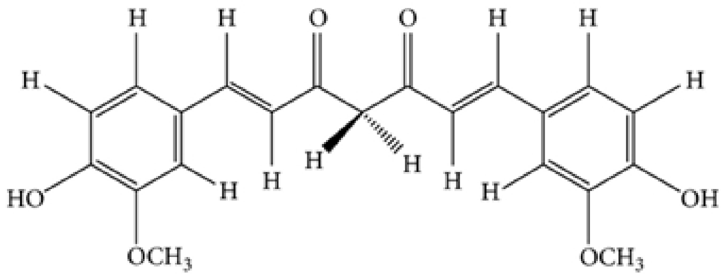
Abstract:

Curcuma longa Linnaeus (turmeric) is a type of most useful herbal medicinal plant belonging to the Zingiberaceae family. Curcumin is obtained from solvent extraction of ground rhizome from the turmeric plant. The exclusive molecular structure of curcumin has made it to be a biochemical compound with significant antioxidative and anti-inflammatory properties. Furthermore, there's ample evidence suggesting its efficacy as a potential anti-microbial, antifungal and antiulcer agent and thus suggests its action to forestall and protect from various cancers, diabetes, allergies, arthritis, chronic diseases, and neurodegenerative disorders. For these medicinal properties, curcumin has received interest from both the medical and scientific world. Curcumin's bioavailability is poor because it is quickly metabolized within the intestine and liver. Extracts from black pepper, called piperine, the primary active component, when combined with curcumin have been shown to boost curcumin's bioavailability by 2000%. Since multi-targeted therapy is more effective than mono targeted therapy, curcumin incorporates a promising scope for future research.

Keywords: Curcumin, Antioxidant, Anti-Inflammatory, Anti-Microbial, Anticancer

Introduction:

Curcumin is an active, yellow-coloured, polyphenolic, curcuminoid compound, (Fig 1) a naturally occurring plant pigment, that is mostly found in the roots of turmeric (*Curcuma longa* L.), an important folk medicinal & spice plant, widely cultivated in Asia (Prasad and Aggarwal 2011). Curcumin is a multi-functional phytochemical that has various inter-related health benefits including anti-oxidant, anti-inflammatory, anti-neoplastic, anti-diabetic, anti-apoptotic, immunomodulatory, and painkiller effects (Hewlings and Kalman 2017). Among these, anti-oxidant and anti-inflammatory functions are two major principles of this compound (Menon and Sudheer 2007). In various cell-culture and animal-model based studies and clinical trials, it has been observed by the scientific communities that curcumin is able to sequester reactive oxygen (ROS) and nitrogen (RNS) species by using ROS generating enzymes like cyclooxygenase & lipoxygenases that help to prevent the oxidative stress-mediated damage of cell membrane, protein, lipid, DNA, haemoglobin etc (Wal *et al.* 2019). It also increases the level of enzymatic antioxidants like catalase, peroxidase, and superoxide mutase (Lin *et al.* 2019, Meshkibaf *et al.* 2019, Jagetia and Rajanikant 2015, Akinyemi *et al.* 2018). That's how curcumin can reduce inflammation and be an excellent component of drugs designed to cure ailments including tumours, atherosclerosis, Crohn's disease, ulcer, rheumatoid arthritis, inflammatory bowel disease, acquired immunodeficiency syndrome (AIDS), psoriasis, diabetes, pancreatitis, neurodegenerative diseases, and other diseases of our body-organs like heart, lungs, liver, kidneys, and brain (Gupta *et al.* 2013, Peng *et al.* 2021). Thus, curcumin is not only a good alternative to the excessive use of synthetic chemical drugs but also, it doesn't have any side-effect like conventional chemical compounds. In this review, we have broadly explained all health-benefit related effects of curcumin along with a special emphasis on its antioxidant properties. The optimum potential of curcumin is limited due to its poor bioavailability and less solubility in aqueous medium. Curcumin has a rapid metabolism and the small portion of substance that is absorbed is extensively bio-transformed into its water-soluble metabolites, glucuronides, and sulfates (Vázquez-Fresno *et al.* 2019). So different strategies have been developed to enhance its efficacy and bioavailability, to increase oral and GI absorption, and to reduce the rate of clearance from the body (Del Prado-Audelo *et al.* 2019, Mirzaei *et al.* 2017, Stoha *et al.* 2020). As curcumin is fat-soluble, several delivery systems have been developed to obtain a number of formulations by mixing curcumin with different materials, including adjuvants, such as piperine (Mirzaei *et al.* 2017, Stoha *et al.* 2020).



Chemical structure of curcumin

Effects of curcumin

Cardiovascular effect: Curcumin can protect us from different cardiovascular disorders (CVDs) by reducing various components of lipids like triglycerides, cholesterol etc, lowering the chance of lipid peroxidation, plasma membrane damage, and platelet aggregation (Qin *et al.* 2017, Cox *et al.* 2022). These effects have been found also with minimum doses of turmeric, without any toxic effect. A comparative study done on 18 rabbits suffering from atherosclerosis was applied with low-dose turmeric extract exhibited less susceptibility of low-density lipoprotein (LDL) to lipid peroxidation, further decreasing plasma LDL cholesterol and triglyceride levels. But, surprisingly, the high dose of curcumin did not lower the lipid peroxidation of LDL, though at a higher concentration of application, cholesterol and triglyceride level was decreased (of note, the decrease was lesser than the low dose) (Ramírez-Tortosa *et al.* 1999). Existing studies depict that curcumin may reduce cholesterol uptake in the intestines and is responsible for the higher conversion of cholesterol to bile acids in our liver via activation of cholesterol 7a-hydroxylase (Chambers *et al.* 2019, Kim and Kim 2010). The NF-κB pathway in M1-macrophages (pro-inflammatory) along with activating M2 phenotypes (anti-inflammatory) (Zhou *et al.* 2015). It is found that turmeric can inhibit platelet aggregation most probably by activation of prostacyclin synthesis and prevention of Thromboxane synthesis (Shah *et al.* 1999, Srivastava *et al.* 1986). These literature evidences suggest the potent action of curcumin to prevent cardiovascular diseases.

Antidermatopathy effect: For skin infections, fresh turmeric juice can act as an anti-parasitic against various pathogens (Moghadamtousi *et al.* 2014). *Curcuma longa* L. leaves have good promise as an antifungal agent that could be used as a therapeutic remedy against human pathogenic fungi on account of its various *in vitro* and *in vivo* antifungal properties, viz., strong fungicidal action, long shells-life, tolerability of heavy inoculum density, thermostability, a broad range of antidermatophytic activity and absence of any adverse effects. Curcumin obtained from the turmeric rhizome has shown to possess the ability to protect the skin from harmful UV-induced effects by displaying antimutagen, antioxidant, free radical scavenging, anti-inflammatory and anti-carcinogenic properties (Amalraj *et al.* 2016).

Roles of curcumin:

Pregnancy-related disorders

- preterm birth
- depression
- foetal growth
- gestational diabetes mellitus (GDM)
- preeclampsia (PE)

anti-toxicant

hepatoprotective

anti-inflammatory

antioxidant

immunomodulatory

antiangiogenic

antiapoptotic

anti-hypertensive

neuroprotective

antidiabetic

Pregnancy and Lactation: Much research is not done about the safety of the consumption of turmeric during pregnancy. Based on a study on pregnant mice in 2017, curcumin has some beneficial effects in pregnancy like-increased fetal & placental weight, increased number of births of live children, reduced blood pressure, etc (Qi *et al.* 2020). But there are some risks of consuming curcumin as it alters estrogen hormone levels leading to pregnancy loss. The limited amount in a normal meal does not harm so much.

Antidiabetic effect: Curcumin generally protects from galactose-induced cataract formation at very low concentrations (Liu *et al.* 2017). Turmeric, as well as curcumin, can reduce glucose levels in blood in alloxan-induced diabetes in mice (Arun and Nalini 2002). Turmeric-product also helps to decrease advanced glycation end products induced complications in case of diabetes mellitus (Yang *et al.* 2019). Turmeric rhizome powder is very useful with Amla juice and honey in diabetes mellitus. The ingestion of 6g *Curcuma longa* increased postprandial serum insulin levels but did not seem to affect plasma glucose level or GI, in healthy subjects (Wickenberg *et al.* 2010). The results describe that turmeric may have an effect on the secretion of insulin hormone. The active principles in the rhizome of Turmeric plant viz; curcuminoids lower lipid peroxidation by maintaining the activities of antioxidant enzymes like superoxide dismutase, catalase and glutathione peroxidase at a higher level (El-Bahr 2015). Various experimental studies indicate turmeric contains different secondary metabolites like curcuminoids, glycosides, terpenoids, flavonoids etc (Oghenejobo *et al.* 2017). The isopropanol and acetone extract of *Curcuma longa* is found to inhibit mainly the enzyme Human Pancreatic Amylase (HPA). This inhibitory action on HPA causes a reduction in starch hydrolysis leading to lowered glucose levels (Ponnusamy *et al.* 2011).

Gastrointestinal effect: The fresh juice of turmeric is considered to be anthelmintic (Srivastava *et al.* 2022). The curcumin acts through nuclear factor (NF)-kB inhibition and it reduces the production of adhesion molecules and inflammatory cytokines, resulting in the amelioration of gastric injury in NSAIDs-induced gastropathy in rats (Thong-Ngam *et al.* 2012). It protects from gastric mucosal damage and also reduces leucocyte adhesions and intercellular adhesion molecule 1 and tumour necrosis factor (TNF)-a production after curcumin administration (Kumar *et al.* 1998). p-tolymethylcarbinol, a turmeric component, increased gastrin, secretin, bicarbonate, and pancreatic enzyme secretion and Sodium-curcuminate inhibited intestinal spasm (Shukla *et al.* 2017). Turmeric has also been found to inhibit ulcer formation due to stress, alcohol, pyloric ligation, and reserpine, increasing mucus of the gastric wall in mice resulting in these gastrointestinal disorders (Yadav *et al.* 2013). Curcumin extract tablet reduced IBS prevalence and abdominal discomfort score significantly between baseline and after treatment of eight weeks. There was a significant increase in the IBS quality of life (QOL) scales (Bundy *et al.* 2004). In the case of liver insult in male mice, curcumin protects from APAP induced hepatitis through the improvement of liver histopathology by reduced oxidative stress, decreased liver inflammation, and restoration of GSH (Appleton and Day 2019).

Anticancer activity: The anti-neoplastic effects of turmeric are due to direct antioxidant and ROS scavenging effects, and also due to their ability to indirectly improve levels of glutathione and thus aiding in hepatic detoxification of mutagens and carcinogens, and hence preventing nitrosamine formation (Piper *et al.* 1998). Anti-cancer effect of curcumin is because of its involvement in several biological pathways of mutagenesis, oncogene expression, cell cycle regulation, apoptosis, tumorigenesis and metastasis. Apoptosis was associated with the modulation of pro- and anti-apoptotic molecules such as increased Bax and reduced Bcl-2 expression, generation of ROS and caspase-3 activation after curcumin treatement (Chen *et al.* 2010). Curcumin prevents uncontrolled cell proliferation in multiple cancers and is an inhibitor of the transcription factor NF-B and downstream gene products like c-myc, Bcl-2, COX-2, NOS, cyclin D1, TNF-a, interleukins and MMP-9 (Sa and Das 2008). Besides, curcumin affects a variety of growth factor receptors and cell adhesion molecules involved in tumour growth, angiogenesis and metastasis. Curcumin recruits anti-tumour activity in various malignant cells by changing the unregulated cell cycle via either of these three means cyclin-dependent, p53 dependent and p53 independent pathways. The key-regulatory effectiveness of curcumin on the signal transduction pathway of cell cycle makes it a multi-functional remedy in the field of treatment of cancer. The phytochemical derived from *Curcuma longa* could connect with these novel targets and show improvement in chemotherapy. In addition to it, curcumin is found to be well tolerated in humans. That's why EGFR-miRNA-autophagy and cancer stem cell-based therapy along with turmeric extract may be one of the novel technologies in the therapeutic strategy of lung cancer (Giordano and Tommonaro 2019).

Antifungal activity: Application of curcumin in plant tissue culture showed that turmeric at the 0.8 and 1.0 g/L had prominent inhibitory activity against some fungal contaminations (Moghadamtousi *et al.* 2016). The methanol extract of turmeric showed a protective function against *Cryptococcus neoformans* and *Candida albicans* with MIC values of 128 and 256 μg/mL, respectively (Moghadamtousi *et al.* 2016). The study of hexane extract of *C. longa* at 1000 mg/L demonstrated antifungal effect against *Rhizoctonia solani*, fungus, and *Erysiphe graminis*. it had been also shown that 1000 mg/L of ester extract of *C. longa* exhibited an inhibitory effect against *R. solani, Puccinia recondita, , P. infestans and Botrytis cinerea*. Curcumin at 500 mg/L also demonstrated antifungal activity against *R. solani, P. recondita, and P. infestans*. Curcumin and turmeric oil act against two phytophagous fungi *Fusarium solani* and *Helminthosporium oryzae* (Revathi and Malathy 2013). Turmeric oil exhibited the foremost effective antifungal activity against *F. solani and H. oryzae*having with an IC_{50} value of 19.73 μg/mL and 12.7 μg/mL, respectively. It was experimentally found that isolated 18-month-old and freshly distilled oil extracted from the rhizome of turmeric had a potent antifungal effect against 29 clinical isolates of dermatophytes with MIC values of 7.2 and 7.8 mg/mL, respectively (Apisariyakul *et al.* 1995). The development of some resistant strains of species of *Candida* against already available antifungal drugs created a critical problem for generating therapeutic strategies. That's why searching for new anti-*Candida* substances is really a cumbersome job (Calderone *et al.* 2014). The study of curcumin against 14 strains of *Candida* including 4 ATCC strains and 10 clinical isolates showed that curcumin could be a potent fungicide compound against *Candida* species having MIC ranging from 250 to 2000 μg/mL (Neelofar *et al.* 2011). During another experiment, it was found that the anti-Candida activity of curcumin was against 38 different strains of *Candida* consisting of some fluconazole resistant strains and clinical isolates of *C. albicans, C. glabrata, C. krusei, C. tropicalis, and C.*

guilliermondii. The MIC90 values for the resistant and sensitive strains were found to be 250–650 and 250–500 μg/mL, respectively (Paul *et al.* 2018). Intracellular acidification via inhibition of H^+-extrusion was identified as a possible mechanism for necrobiosis of *Candida* species. The event of hyphae development was proved to be inhibited by curcumin by targeting the worldwide suppressor thymidine uptake 1 (TUP1). One of the key complications during therapies against chronic asthma is oropharyngeal candidiasis (Karaman *et al.* 2011). Curcumin as a possible candidate for the treatment of candidiasis with anti-inflammatory activity was studied during a murine model of asthma.

Curcumin as a potent anti-oxidant: Antioxidant and anti-inflammatory properties are two major principles of curcumin. Antioxidant effect of curcumin was reported as early as 1975 (Banerjee *et al.* 2015). It can protect haemoglobin from oxidation. *In vitro*, curcumin can significantly inhibit the generation of reactive oxygen species (ROS) like superoxide anions, H_2O_2 and nitrite radical generation by activated macrophages, which play an important role in inflammation. Curcumin also lowers the production of ROS *in vivo*. Its derivatives, de-methoxy-curcumin and bis-de-methoxy-curcumin also have an antioxidant effect. Pure curcumin has more potent superoxide anion scavenging activity than de-methoxy-curcumin or bis-de-methoxy-curcumin. Curcumin exerts a powerful inhibitory effect against H_2O_2-induced damage in human keratinocytes from xanthine oxidase injury and fibroblasts31 and in NG 108-15 cells80 (Phan *et al.* 2001). Water and fat-soluble extracts of turmeric and its curcumin component exhibit strong antioxidant activity. A study of ischemia in the feline heart demonstrated that curcumin pre-treatment decreased ischemia-induced changes in the heart. An *in vitro* study measuring the effect of curcuma on endothelial heme oxygenase-1, an inducible stress protein, was conducted utilizing bovine aortic endothelial cells. Incubation (18 hours) with curcumin resulted in enhanced cellular resistance to oxidative damage (Fuloria *et al.* 2022). Curcumin not only strengthens the anti-oxidative defence system of body, but also the phenolic compounds isolated from turmeric help to preserve food for a longer time by protecting it from peroxide formation. In the case of an experiment carried out on brain tissue and liver microsomes of rats, it was found that the methoxy group attached to the phenolic curcuminoids had a prominent effect to prevent lipid peroxidation. Scientists believe that the superb antioxidant features of curcumin are mainly due to its H-atom donation from the phenolic group (Barzegar 2012). Studies indicate that curcumin inhibits peroxidation mainly through its iron binding capacity. In the presence of curcumin, the oxidation of linoleic acid is very slow. It works in a way that binds free radicals and it also donates a hydrogen atom. Curcumin has the property of donating electrons in order to neutralize free radicals by creating stable products, thus breaking a chain reaction of creating free radicals in a living organism. Curcumin's ability to capture hydrogen peroxide is higher than that of the commercial antioxidants (BHA, BHT, vitamin E) at the same concentration. An equilibrium between oxidants and antioxidants are required for the smooth functioning of human reproductive system (Kurutas 2016). In many experiments, it has been shown that curcumin could protect the structural integrity and functional activity of the spermatozoa particularly when oxidative damage is increased. Curcumin is also used for cryopreservation of semen (Santonastaso *et al.* 2021). Moreover, curcumin can be used for the prevention of neurodegenerative diseases as it has an anti-oxidative effect on astrocyte cells and neural glial cells of the central nervous system (Cole *et al.* 2007).

Conclusion:

As the human body is a system, an equilibrium between free radical and anti-oxidants (enzymatic and non-enzymatic) should be maintained. There are different phytochemicals and vitamins which are or can be included in the diet as anti-oxidants (Prasad and Aggarwal 2011). Turmeric is a plant that is cultivated for hundreds of years as spice and medicinal plant. Curcumin is a plant-derived biochemical isolated from rhizomes of turmeric, with a little or negligible side effects. It is a natural substitute to cure different diseases. In recent studies and experiments, its medicinal potential is revealing day by day. Among the generalized protective properties of curcumin, anti-oxidant and anti-inflammatory effects are the main.

From carcinogenesis to DNA damage and from mutagenesis to chronic diseases; all are often associated with free-radical damage. Curcumin is a potent therapeutic against such damage and reduces inflammation (Sarkar *et al.* 2016). The mechanism of curcumin is mainly due to directly targeting the transcription factor NF-κB, which is called the inflammatory master switch. It also shows its versatile effects in both *in vivo* and *in vitro* systems. For example, new findings suggested that curcumin is a source of natural anti-microbials. Not only as a non-steroidal anti-inflammatory drug (NSAID), in various countries, curcumin is widely used to preserve the nutritive value of food for a long time & increase the shelf-life of perishable foods due to its anti-oxidant property (Hewlings and Kalman 2017).

CARDIOVASCULAR EFFECT:

- triglycerides, cholesterol
- reduces lipid peroxidation
- inhibits plasma membrane damage
- decreases plasma LDL cholesterol and triglyceride levels
- reduces cholesterol uptake in the intestine
- causes higher conversion of cholesterol to bile acids
- inhibits platelet aggregation
- activates prostacyclin synthesis and
- prevents thromboxane synthesis

ANTIDIABETIC EFFECT:

- protects from galactose-induced cataract formation
- reduce glucose levels in blood
- decreases advanced glycation end products induced complications
- increases postprandial serum insulin levels
- lowers lipid peroxidation by maintaining the activities of SOD, catalase and glutathione peroxidase
- inhibits Human Pancreatic Amylase (HPA)
- causes a reduction in starch hydrolysis

GASTROINTESTINAL EFFECT:

- inhibits nuclear factor (NF)-kB
- reduces the production of adhesion molecules
- reduces inflammatory cytokines
- results in amelioration of gastric injury
- protects from gastric mucosal damage
- reduces leucocyte adhesions and intercellular adhesion molecule
- reduces tumour necrosis factor (TNF)-a
- increases gastrin, secretin, bicarbonate, and pancreatic enzyme secretion
- inhibits ulcer formation due to stress, alcohol, pyloric ligation, and reserpine
- reduces IBS prevalence and abdominal discomfort score
- improves liver histopathology by reduced oxidative stress

ANTIDERMATOPATHY EFFECT:

- protects from harmful UV radiation
- antimutagen
- antioxidant
- free radical scavenger
- anti-inflammatory
- anti-carcinogenic

PREGNANCY:

- not recommended to use without medical supervision

ANTICANCER ACTIVITY:

- prevents uncontrolled cell proliferation
- inhibits transcription factor NF-B and downstream gene products like c-myc, Bcl-2, COX-2, NOS, cyclin D1, TNF-a, interleukins and MMP-9
- affects a variety of growth factor receptors and
- affects cell adhesion molecules involved in tumour growth, angiogenesis and metastasis
- recruits anti-tumour activity in various malignant cells by changing the unregulated cell cycle

ANTIFUNGAL ACTIVITY:

- *Cryptococcus neoformans*
- *Candida albicans*
- *C. glabrata*
- *C. krusei*
- *C. tropicalis*
- *C. guilliermondii.*
- *Rhizoctonia solani*
- *Erysiphe graminis*
- *Puccinia recondita,*
- *P. infestans*
- *Botrytis cinerea*
- *Fusarium solani*
- *Helminthosporium oryzae*

ANTIOXIDANT EFFECT:

- protects haemoglobin from oxidation
- inhibits the generation of reactive oxygen species (ROS)
- decreases ischemia-induced changes in the heart
- enhances cellular resistance to oxidative damage
- strengthens the anti-oxidative defence system of body
- inhibits peroxidation mainly through the iron binding capacity
- lowers the oxidation of linoleic acid
- binds free radicals and donates a hydrogen atom
- breaks a chain reaction of creating free radicals
- captures hydrogen peroxide at higher rate than commercial antioxidants
- protect the structural integrity and functional activity of the spermatozoa
- used for cryopreservation of semen

EFFECTS OF CURCUMIN ON HUMAN HEALTH

The anti-oxidative role of curcumin should be studied further to well-characterize the comprehensive role of curcumin in combating the oxidative damage of the body. It is found that oral efficacy of curcumin is limited in humans that other fat-soluble antioxidants like vitamin E (α-tocopherol). Use of other agents along with curcumin should be further investigated to increase efficacy & bioavailability to the body. All these situations make curcumin a premium therapeutically important phytochemical and a potential factor for the treatment of many diseases. Further studies need to reveal curcumin's effect during pregnancy. Multidisciplinary scientific studies are also required to understand the complex network of natural product and human physiology. Pharmacological advancements are also to be implemented to increase the bioavailability and efficacy of curcumin in human.

Acknowledgement:

The authors acknowledge their respective departments and Institute. This review received no external funding.

Authors Contribution:

Conceptualization, JR and SD; PubMed search, TM and JR; writing—draft preparation, JR, TM and SD; writing—review and editing, JR, TM and SD; supervision and critical revision SD. All authors have read and agreed to the published version of the manuscript.

References:

1. Prasad S, Aggarwal BB (2011) Turmeric, the Golden Spice: From Traditional Medicine to Modern Medicine. In I. F. F. Benzie (Eds.) et. al., Herbal Medicine: Biomolecular and Clinical Aspects. (2nd ed.). CRC Press/Taylor & Francis.
2. Hewlings SJ, Kalman DS (2017) Curcumin: A Review of Its Effects on Human Health. Foods (Basel, Switzerland), 6(10): 92. https://doi.org/10.3390/foods6100092
3. Menon VP, Sudheer AR (2007) Antioxidant and anti-inflammatory properties of curcumin. Advances in Experimental Medicine and Biology 595: 105–125. https://doi.org/10.1007/978-0-387-46401-5_3
4. Wal P, Saraswat N, Pal RS, Wal A, Chaubey M. (2019) A detailed insight of the anti-inflammatory effects of curcumin with the assessment of parameters, sources of Ros and associated mechanisms. Open Medicine Journal, 6(1): 64–76.
5. https://doi.org/10.2174/1874220301906010064

6. Lin X, Bai D, Wei Z, Zhang Y, Huang Y, Deng H, Huang X. (2019) Curcumin attenuates oxidative stress in RAW264.7 cells by increasing the activity of antioxidant enzymes and activating the Nrf2-Keap1 pathway. PloS One, 14(5): e0216711. https://doi.org/10.1371/journal.pone.0216711
7. Meshkibaf MH, Maleknia M, Noroozi S. (2019) Effect of curcumin on gene expression and protein level of methionine sulfoxide reductase A (MSRA), SOD, CAT and GPx in Freund's adjuvant inflammation-induced male rats. Journal of Inflammation Research, 12: 241–249. https://doi.org/10.2147/JIR.S212577
8. Jagetia GC, Rajanikant GK (2015) Curcumin Stimulates the Antioxidant Mechanisms in Mouse Skin Exposed to Fractionated γ-Irradiation. Antioxidants (Basel, Switzerland), 4(1): 25–41. https://doi.org/10.3390/antiox4010025
9. Akinyemi AJ, Oboh G, Ogunsuyi O, Abolaji AO, Udofia A. (2018) Curcumin-supplemented diets improve antioxidant enzymes and alter acetylcholinesterase genes expression level in Drosophila melanogaster model. Metabolic Brain Disease, 33(2): 369–375. https://doi.org/10.1007/s11011-017-0100-7
10. Gupta SC, Patchva S, Aggarwal BB (2013) Therapeutic roles of curcumin: lessons learned from clinical trials. The AAPS Journal, 15(1): 195–218. https://doi.org/10.1208/s12248-012-9432-8
11. Peng Y, Ao M, Dong B, Jiang Y, Yu L, Chen Z, Hu C, Xu R (2021) Anti-Inflammatory Effects of Curcumin in the Inflammatory Diseases: Status, Limitations and Countermeasures. Drug Design, Development and Therapy, 15: 4503–4525. https://doi.org/10.2147/DDDT.S327378
12. Vázquez-Fresno R, Rosana ARR, Sajed T, Onookome-Okome T, Wishart NA, Wishart DS (2019) Herbs and Spices-Biomarkers of Intake Based on Human Intervention Studies–A Systematic Review. Genes and Nutrition, 14:18. https://doi.org/10.1186/s12263-019-0636-8
13. Del Prado-Audelo ML, Caballero-Florán IH, Meza-Toledo JA., Mendoza-Muñoz N, Torres MG, Florán B, Cortés H, Leyva-Gómez G (2019) Formulations of Curcumin Nanoparticles for Brain Diseases. Biomolecules, 9:56.https://doi/10.3390/biom9020056
14. Mirzaei H, Shakeri A, Rashidi B, Jalili A, Banikazemi Z, Sahebkar A (2017) Phytosomal Curcumin: A Review of Pharmacokinetic, Experimental and Clinical

Studies. Biomedicine and Pharmacotherapy, 85:102–112. https://:doi/10.1016/j.biopha.2016.11.098

15. Stohs SJ, Chen O, Ray SD, Ji J, Bucci LR, Preuss HG (2020) Highly Bioavailable Forms of Curcumin and Promising Avenues for Curcumin-Based Research and Application: A Review. Molecules, 25:1397. https://doi:10.3390/molecules25061397
16. Qin S, Huang L, Gong J, Shen S, Huang J, Ren H, Hu H (2017) Efficacy and safety of turmeric and curcumin in lowering blood lipid levels in patients with cardiovascular risk factors: a meta-analysis of randomized controlled trials. Nutrition Journal, 16(1): 68. https://doi.org/10.1186/s12937-017-0293-y
17. Cox FF, Misiou A, Vierkant A, Ale-Agha N, Grandoch M, Haendeler J, Altschmied, J. (2022) Protective Effects of Curcumin in Cardiovascular Diseases-Impact on Oxidative Stress and Mitochondria. Cells, 11(3): 342. https://doi.org/10.3390/cells11030342
18. Ramírez-Tortosa, M. C., Mesa, M. D., Aguilera, M. C., Quiles, J. L., Baró, L., Ramirez-Tortosa, C. L., Martinez-Victoria, E., & Gil, A. (1999) Oral administration of a turmeric extract inhibits LDL oxidation and has hypocholesterolemic effects in rabbits with experimental atherosclerosis. Atherosclerosis, 147(2): 371–378. https://doi.org/10.1016/s0021-9150(99)00207-5
19. Chambers KF, Day PE, Aboufarrag HT, Kroon PA. (2019) Polyphenol Effects on Cholesterol Metabolism via Bile Acid Biosynthesis, CYP7A1: A Review. Nutrients, 11(11): 2588. https://doi.org/10.3390/nu11112588
20. Kim M, Kim Y. (2010) Hypocholesterolemic effects of curcumin via up-regulation of cholesterol 7a-hydroxylase in rats fed a high fat diet. Nutrition Research and Practice, 4(3): 191–195. https://doi.org/10.4162/nrp.2010.4.3.191
21. Zhou Y, Zhang T, Wang X, Wei X, Chen Y, Guo L, Zhang J, Wang C. (2015) Curcumin Modulates Macrophage Polarization Through the Inhibition of the Toll-Like Receptor 4 Expression and its Signaling Pathways. Cellular physiology and biochemistry : International Journal of Experimental Cellular Physiology, Biochemistry, and Pharmacology, 36(2): 631–641. https://doi.org/10.1159/000430126
22. Shah BH, Nawaz Z, Pertani SA, Roomi A, Mahmood H, Saeed SA, Gilani AH. (1999) Inhibitory effect of curcumin, a food spice from turmeric, on platelet-activating factor- and arachidonic acid-mediated platelet aggregation through inhibition of

thromboxane formation and Ca2+ signaling. Biochemical Pharmacology, 58(7): 1167–1172. https://doi.org/10.1016/s0006-2952(99)00206-3

23. Srivastava R, Puri V, Srimal RC, Dhawan BN (1986) Effect of curcumin on platelet aggregation and vascular prostacyclin synthesis. Arzneimittel-Forschung, 36(4): 715–717.
24. Moghadamtousi SZ, Kadir HA, Hassandarvish P, Tajik H, Abubakar S, Zandi K (2014) A review on antibacterial, antiviral, and antifungal activity of curcumin. Biomedical Research International, 2014: 186864. https://doi.org/10.1155/2014/186864
25. Amalraj A, Pius A, Gopi S, Gopi S (2016) Biological activities of curcuminoids, other biomolecules from turmeric and their derivatives - A review. Journal of Traditional and Complementary Medicine, 7(2): 205–233. https://doi.org/10.1016/j.jtcme.2016.05.005
26. Qi L, Jiang J, Zhang J, Zhang L, Wang T (2020) Maternal curcumin supplementation ameliorates placental function and fetal growth in mice with intrauterine growth retardation†. Biology of Reproduction, 102(5): 1090–1101. https://doi.org/10.1093/biolre/ioaa005
27. Liu XF, Hao JL, Xie T, Mukhtar NJ, Zhang W, Malik TH, Lu CW, Zhou DD (2017) Curcumin, A Potential Therapeutic Candidate for Anterior Segment Eye Diseases: A Review. Frontiers in Pharmacology, 8: 66. https://doi.org/10.3389/fphar.2017.00066
28. Arun N, Nalini N (2002) Efficacy of turmeric on blood sugar and polyol pathway in diabetic albino rats. Plant Foods for Human Nutrition (Dordrecht, Netherlands), 57(1): 41–52. https://doi.org/10.1023/a:1013106527829
29. Yang P, Feng J, Peng, Q., Liu, X., & Fan, Z. (2019). Advanced Glycation End Products: Potential Mechanism and Therapeutic Target in Cardiovascular Complications under Diabetes. Oxidative Medicine and Cellular Longevity, 2019, 9570616. https://doi.org/10.1155/2019/9570616
30. Wickenberg J, Ingemansson SL, Hlebowicz J (2010) Effects of Curcuma longa (turmeric) on postprandial plasma glucose and insulin in healthy subjects. Nutrition Journal, 9: 43. https://doi.org/10.1186/1475-2891-9-43
31. El-Bahr SM (2015) Effect of curcumin on hepatic antioxidant enzymes activities and gene expressions in rats intoxicated with aflatoxin B1. Phytotherapy Research : PTR, 29(1): 134–140. https://doi.org/10.1002/ptr.5239

32. Oghenejobo M, Opajobi OA, Bethel OUS, Uzoegbu U (2017) Antibacterial evaluation, phytochemical screening and ascorbic acid assay of turmeric (Curcuma longa). MOJ Bioequiv Availab. 4(2):232-239. https://doi.org/10.15406/mojbb.2017.04.00063
33. Ponnusamy S, Ravindran R, Zinjarde S, Bhargava S, Ravi Kumar A (2011) Evaluation of traditional Indian antidiabetic medicinal plants for human pancreatic amylase inhibitory effect in vitro. Evidence-Based Complementary and Alternative Medicine: eCAM, 2011: 515647. https://doi.org/10.1155/2011/515647
34. Srivastava BBL, Ripanda AS, Mwanga HM (2022) Ethnomedicinal, Phytochemistry and Antiviral Potential of Turmeric (Curcuma longa). *Compounds*. 2(3): 200-221. https://doi.org/10.3390/compounds2030017
35. Thong-Ngam D, Choochuai S, Patumraj S, Chayanupatkul M, Klaikeaw N (2012) Curcumin prevents indomethacin-induced gastropathy in rats. World Journal of Gastroenterology, 18(13): 1479–1484. https://doi.org/10.3748/wjg.v18.i13.1479
36. Kumar A, Dhawan S, Hardegen NJ, Aggarwal BB (1998) Curcumin (Diferuloylmethane) inhibition of tumor necrosis factor (TNF)-mediated adhesion of monocytes to endothelial cells by suppression of cell surface expression of adhesion molecules and of nuclear factor-kappaB activation. Biochemical Pharmacology, 55(6): 775–783. https://doi.org/10.1016/s0006-2952(97)00557-1
37. Shukla G, Yaparthy N, Giri N, Santosh G, Sampath CJK (2017) Curcumet capsules; an effective supplementation for various life style disorders & as a potent Antioxidant. International Journal of Research in Pharmacology & Pharmacotherapeutics, 6(2): 236-241.
38. Yadav SK, Sah AK, Jha RK, Sah P, Shah DK (2013) Turmeric (curcumin) remedies gastroprotective action. Pharmacognosy Reviews, 7(13): 42–46. https://doi.org/10.4103/0973-7847.112843
39. Bundy R, Walker AF, Middleton RW, Booth J (2004) Turmeric extract may improve irritable bowel syndrome symptomology in otherwise healthy adults: a pilot study. Journal of Alternative and Complementary Medicine (New York, N.Y.), 10(6): 1015–1018. https://doi.org/10.1089/acm.2004.10.1015
40. Appleton L., Day AS (2019) Re: A Meta-Analysis of the Clinical Use of Curcumin for Irritable Bowel Syndrome. Journal of Clinical Medicine, 8(11): 1885. https://doi.org/10.3390/jcm8111885

41. Piper JT, Singhal SS, Salameh MS, Torman RT, Awasthi YC, Awasthi S (1998) Mechanisms of anticarcinogenic properties of curcumin: the effect of curcumin on glutathione linked detoxification enzymes in rat liver. The International Journal of Biochemistry and Cell Biology, 30(4): 445–456. https://doi.org/10.1016/s1357-2725(98)00015-6
42. Chen CC, Hsieh MS, Hsuuw YD, Huang FJ, Chan WH (2010). Hazardous Effects of Curcumin on Mouse Embryonic Development through a Mitochondria-Dependent Apoptotic Signalling Pathway. International Journal of Molecular Science, 11:2839–2855. https://doi/10.3390/ijms11082839
43. Sa G, Das T (2008) Anti cancer effects of curcumin: cycle of life and death. Cell Division, 3: 14. https://doi.org/10.1186/1747-1028-3-14
44. Giordano A, Tommonaro G (2019) Curcumin and Cancer. Nutrients, 11(10): 2376. https://doi.org/10.3390/nu11102376
45. Revathi S, Malathy NS (2013) Antibacterial Activity of Rhizome of Curcuma aromatica and Partial Purification of Active Compounds. Indian Journal of Pharmaceutical Sciences, 75(6): 732–735.
46. Apisariyakul A, Vanittanakom N, Buddhasukh D (1995) Antifungal activity of turmeric oil extracted from Curcuma longa (Zingiberaceae). Journal of Ethnopharmacology, 49(3): 163–169. https://doi.org/10.1016/0378-8741(95)01320-2
47. Calderone R, Sun N, Gay-Andrieu F, Groutas W, Weerawarna P, Prasad S, Alex D, Li D. (2014) Antifungal drug discovery: the process and outcomes. Future Microbiology, 9(6): 791–805. https://doi.org/10.2217/fmb.14.32
48. Neelofar K, Shreaz S, Rimple B, Muralidhar S, Nikhat M, Khan LA (2011) Curcumin as a promising anticandidal of clinical interest. Canadian Journal of Microbiology, 57(3): 204–210. https://doi.org/10.1139/W10-117
49. Paul S, Mohanram K, Kannan I (2018) Antifungal activity of curcumin-silver nanoparticles against fluconazole-resistant clinical isolates of Candida species. Ayu, 39(3): 182–186. https://doi.org/10.4103/ayu.AYU_24_18
50. Karaman M, Arıkan Ayyıldız Z, Fırıncı F, Kiray M, Bağrıyanık A, Yilmaz O, Uzuner N, Karaman O (2011) Effects of curcumin on lung histopathology and fungal burden in a mouse model of chronic asthma and oropharyngeal candidiasis. Archives of Medical Research, 42(2): 79–87. https://doi.org/10.1016/j.arcmed.2011.01.011

51. Banerjee A, Ghosh S, Ghosh M (2015) Anti-oxidative effect of turmeric on frying characteristics of soybean oil. Journal of Food Science and Technology, 52(3): 1760–1765. https://doi.org/10.1007/s13197-013-1156-y
52. Phan TT, See P, Lee ST, Chan SY (2001) Protective effects of curcumin against oxidative damage on skin cells in vitro: its implication for wound healing. The Journal of Trauma, 51(5): 927–931. https://doi.org/10.1097/00005373-200111000-00017
53. Fuloria S, Mehta J, Chandel A, Sekar M, Rani NNIM, Begum MY, Subramaniyan V, Chidambaram K, Thangavelu L, Nordin R, Wu YS, Sathasivam KV, Lum PT, Meenakshi DU, Kumarasamy V, Azad AK, Fuloria NK (2022) A Comprehensive Review on the Therapeutic Potential of Curcuma longa Linn. in Relation to its Major Active Constituent Curcumin. Frontiers in Pharmacology, 13: 820806. https://doi.org/10.3389/fphar.2022.820806
54. Barzegar A. (2012). The role of electron-transfer and H-atom donation on the superb antioxidant activity and free radical reaction of curcumin. Food Chemistry, 135(3): 1369–1376. https://doi.org/10.1016/j.foodchem.2012.05.070
55. Kurutas EB (2016) The importance of antioxidants which play the role in cellular response against oxidative/nitrosative stress: current state. Nutrition Journal, 15(1): 71. https://doi.org/10.1186/s12937-016-0186-5
56. Santonastaso M, Mottola F, Iovine C, Colacurci N, Rocco L (2021) Protective Effects of Curcumin on the Outcome of Cryopreservation in Human Sperm. Reproductive Sciences (Thousand Oaks, Calif.), 28(10): 2895–2905. https://doi.org/10.1007/s43032-021-00572-9
57. Cole GM, Teter B, Frautschy SA (2007) Neuroprotective effects of curcumin. Advances in Experimental Medicine and Biology, 595: 197–212. https://doi.org/10.1007/978-0-387-46401-5_8
58. Sarkar A, De R, Mukhopadhyay AK (2016) Curcumin as a potential therapeutic candidate for Helicobacter pylori associated diseases. World Journal of Gastroenterology, 22(9): 2736–2748. https://doi.org/10.3748/wjg.v22.i9.2736

NANOTECHNOLOGY OF FOOD SCIENCE AND ITS VARIOUS APPLICATIONS

Jitendra Pal Singh*[1], Neelam Kumari[2] and Pinki[3]

[1]Department of Physics, School of Sciences, IFTM University, Moradabad-244102, India

[2]Department of Home science, Anubis P.G.College Meerganj Bareilly, Uttar Pradesh India

[3]Department of Home Science, School of Sciences, IFTM University, Moradabad-244102

*Corresponding author E-mail: paljitendra124@gmail.com

Abstract:

The discipline of food science and technology which integrates basic and applied sciences including biology, biotechnology, cell biology, chemistry, computer science, data informatics, engineering, genomics, materials science, microbiology, nutrition, packaging, physics, sensory science, toxicology, etc Nanotechnology is a significant modern technology that supports advancement, contribution, and long-term effects in the fields of agriculture, medicine, and food. Nanomaterials might be at the forefront of both the qualitative as well as quantitative creation of healthier, safer, and high-quality functional foods which are perishable or semi-perishable in nature. With longer food product shelf lives, less contamination, and improved food quality, nanotechnologies outperform traditional food processing methods. Taking into account processing, packaging, security, and storage, this thorough analysis of nanotechnologies for the production of functional foods outlines present trends and the future prospects of advanced nanotechnology in the food industry. By altering the particle size, potential cluster formation, and surface charge of food nanomaterials, nanotechnology applications improve the meal's bioavailability, taste, texture, and consistency. Also included are the conventional methods used to evaluate the effects of nanomaterials in biological systems and the use of nanosensors in smart food packaging to track the quality of the foods being kept.

Introducation:

Nanotechnology is the technology applied in the manipulation of nanomaterials for several purposes, which plays a crucial role in the food and agriculture sectors, contributes to crop improvement, enhances the food quality and safety, and promotes human health through novel and innovative approaches [1]. Owing to the unique physical, chemical, and biological properties with large surface–volume ratio as well as the altered solubility and toxicity when compared with their macroscale counterparts, engineered nanometer-sized particles have gained more attention in medicine, agro-food sectors, sewage water treatments, and other industries [2, 3]. Silver (Ag), gold (Au), zinc oxide (ZnO), titanium dioxide (TiO2), and carbon nanoparticles are manufactured as much as tenfold that of other nanomaterials in amount due to their potential antimicrobial characteristics, being used in air filters, food storage containers, deodorants, bandages, toothpastes, paints, and other home appliances [3, 4]. Besides, the potent antibiotic activity of nanosized copper oxides (nCuO) has resulted in the wide application in commercial nano-biocide products [5].

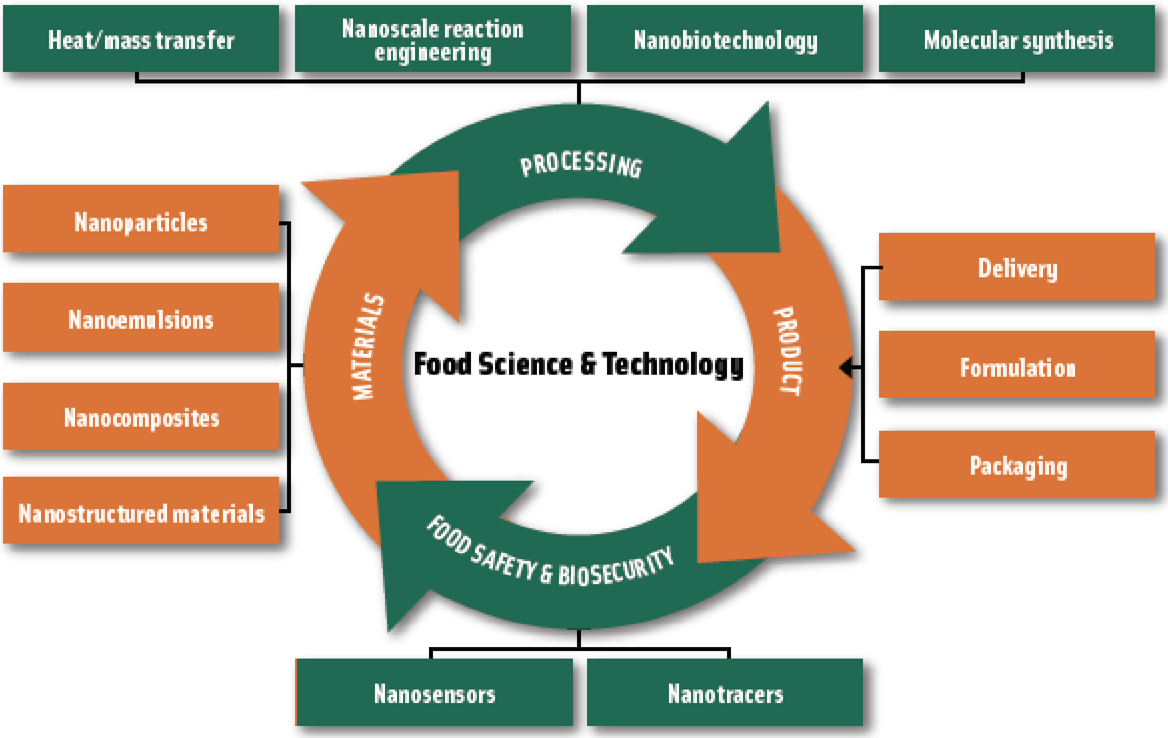


Figure 1: Nanotechnology in food science and technology

Application of Nanotechnology in Food Science

Application of nanotechnology in the food sector can be edited in two major categories which are nanostructured food ingredients and food nanosensing. Nanostructured food ingredients cover a wide range of sectors from food production to food packaging. Such nanostructures can be used as food additives in food processing, carriers for smart nutrient delivery, anti-oxidative agents, anti-caking agents, antimicrobial agents, fillers to improve the mechanical strength and durability of the packaging material, etc[5].though nanosensing of foods can be used to achieve improved food quality and health assessment (Ezhilarasi *et al.,* 2013).

Nanotechnology can be used in many applications within food industry. The application of nanotechnology in this study covers primarily food Processing, food security or preservation, food Packaging and food safety or health (Fig.2)

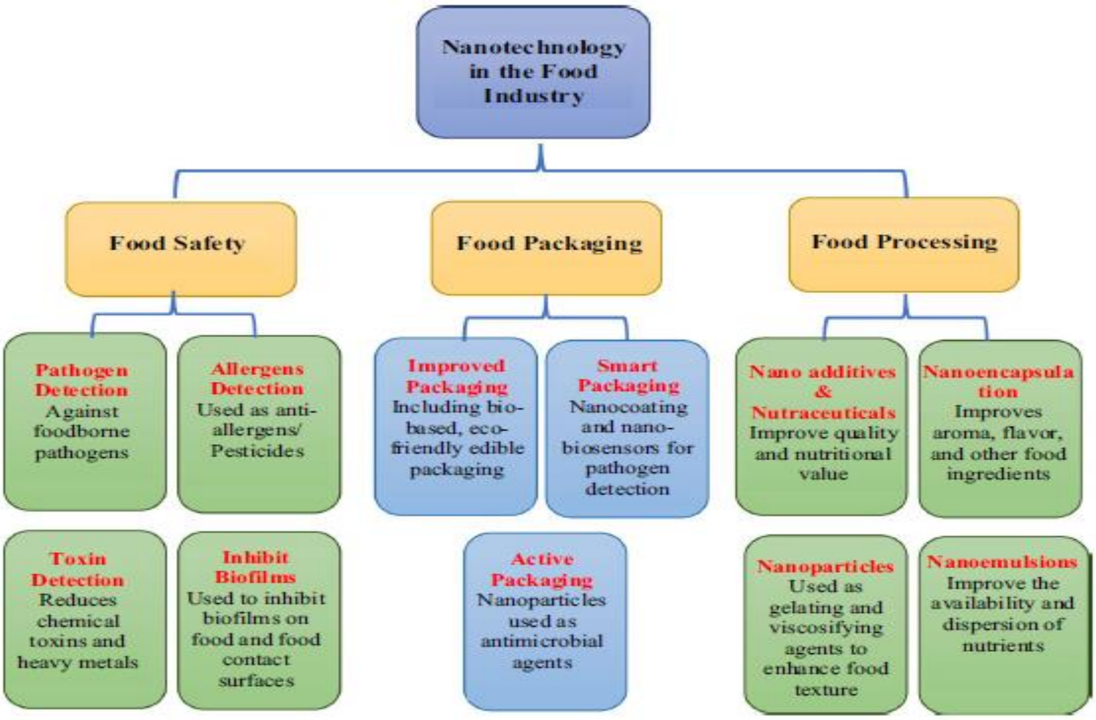


Figure 2: Nanotechnology Application in Food technology

(1) Nanotechnology application for Water Purification

Nanotechnology can be used in water purification. A US company has developed 2nm diameter aluminium oxide nanofibres as a water filtration aid, while a product containing lanthanum nanoparticles can absorb phosphates from aqueous environments. Research at the Centre for Biological and Environmental Nanotechnology (CBEN) has shown that nanoscale iron oxide particles are extremely effective at binding and removing arsenic from groundwater[6].

(2) Nanotechnology application for food packaging

Nano material for food packaging should have little or no moisture and gas permeability in combination with biodegradability resistance to mechanical damage, high strength, among other desirable properties. Nano-based "active" and "smart" food packaging confers numerous benefits compared with conventional methods of packaging; from offering improved packaging materials with enhanced mechanical strengths, barrier characteristics, antimicrobial film to nano sensing for detecting pathogens, as well as informing consumers about food safety status[7]. Applications of nanocomposite materials as bioactive packing and coating materials are typically used to improve food packaging; a number of researchers are interested in assessing the antimicrobial properties of organic materials like bacteriocins, organic acids, and essential oils and their use in polymer matrices for antimicrobial packaging[8, 9]

- **Food safety**
  - **Antimicrobial activity**: Nanoparticles can be used to prevent food spoilage
  - **Nanosensors**: Nanoparticles can detect microbes
  - **Food packaging**: Nanoparticles can be used in packaging to extend shelf life
- **Food quality**
  - **Nutrient delivery**: Nanoparticles can deliver nutrients to food
  - **Fat replacers**: Nanoparticles can reduce fat content in baked goods
  - **Texture, color, and appearance**: Nanoparticles can improve the sensory quality of food
- **Food processing**
  - **Meat tenderization**: Enzyme nanoparticles can break down protein
  - **Time-temperature sensors**: Nanoparticles can monitor food freshness
- **Food security**
  - **Agricultural efficiency**: Nanotechnology can improve agricultural efficiency
  - **Water utilization**: Nanotechnology can improve water utilization
  - **Soil enhancement**: Nanotechnology can improve soil
  - **Food distribution**: Nanotechnology can improve food distribution

(3) Nanotechnology application for food nanosensor

A nanosensor also called a bio-analytical device is an integrated system that consists of different nanostructured materials and biological receptors. In recent years, nanosensors have been utilized in the food processing and packaging industries and have gained much attention due to their integrity, quick detection ability, and low cost. Nanosensors are easily integrated with analytes due to their specificity and high sensitivity. The involvement of different types of nanomaterials, such as nanoparticles (metallic, non-metallic, and metal oxide), nanorods, nanowires, carbon nanotubes, and nanofibers in the development of nanosensors enhances its surface-to-volume ratios, optical, and electrical properties. These sensors have the ability to detect color changes in the food as well as any gases that are being produced due to food spoilage. It has been observed that nanosensors are highly sensitive to various gases such as ammonia, hydrogen, hydrogen sulfide, sulfur dioxide, and nitrogen oxides. Nowadays, nanosensors are widely used in the detection of food-borne pathogens, chemicals, toxins, and pesticides that are present in food products. As compared to conventional sensors, nanosensors are more prominent and efficient due to their high sensitivity and selectivity. Typically, nanosensors consist of electronic (data processing devices) and sensing devices that make them capable of detecting changes in heat, light, gas, and chemicals by converting them into electrical signals. Mostly gas sensors consist of metallic nanoparticles such as gold, platinum, and palladium. Currently, sensors such as electrochemical and biosensors based on metallic nanoparticles, super magnetic nanoparticles, and newly developed nanomaterials (carbon Nanotubes) are used in the detection of different toxins present in food products. Metallic nanoparticles such as silver, gold, copper, platinum, and zinc are commonly used for the formation of sensors[10].

Conclusion:

The purpose of nanotechnology in the food industry is to maximize its application in a number of sectors, including food processing, packaging, preservation, and safety. Nanotechnology is becoming a distinctive answer to a number of problems as developments continue to revolutionize the nanotechnology industry. Nano encapsulation, a method that improves food processing and packaging by enhancing safety while also raising flavor, nutrition, and overall quality, is attracting more and more attention from researchers. The creation of functional foods, which incorporate vitamins and medical components to further improve productivity and health benefits, is another area where nano encapsulation is gaining traction

References:

1. Singh, R., Dutt, S., Sharma, P., Sundramoorthy, A. K., Dubey, A., Singh, A., & Arya, S. (2023). Future of nanotechnology in the food industry: Challenges in processing, packaging, and food safety. *Global Challenges, 7*, 2200209.
2. Biswas, R., Alam, M., Sarkar, A., Haque, M. I., Hasan, M. M., & Hoque, M. (2022). Application of nanotechnology in food: Processing, preservation, packaging, and safety assessment. *Heliyon, 8*, e11795.
3. Pilli, G. D., Elumalai, K., Muthukumar, V. A., & Sundaram, P. S. (2022). A revised analysis of current and emerging nanosuspension technological approaches for cardiovascular medicine. *Beni-Suef University Journal of Basic and Applied Sciences, 11*, 1–12.

4. Abbas, K., Saleh, A., Mohamed, A., & MohdAzhan, N. (2009). The recent advances in nanotechnology and its applications in food processing: A review. *Food, Agriculture & Environment, 7*, 14–17.
5. Al-Fadul, S., & Elneshwy, A. (2010). Use of nanotechnology in food processing, packaging, and safety: A review. *African Journal of Food and Nutritional Sciences, 10*(6).
6. Nile, S. H., Baskar, V., Selvaraj, D., Nile, A., Xiao, J., & Kai, G. (2020). Nanotechnologies in food science: Applications, recent trends, and future perspectives. *Nano-Micro Letters*. https://doi.org/10.1007/s40820-020-0383-9
7. Duncan, T. V. (2011). Applications of nanotechnology in food packaging and food safety: Barrier materials, antimicrobials, and sensors. *Journal of Colloid and Interface Science, 363*, 1–24. https://doi.org/10.1016/j.jcis.2011.07.01
8. Ansari, A. A., et al. (2010). Prospects of nanotechnology in clinical immunodiagnostics. *Sensors, 10*, 6535–6581. https://doi.org/10.3390/s100706535
9. Awuchi, C. G., Twinomhwezi, H., Choudghal, S., Khan, M. G., Yezdani, U., & Akram, M. V. (2020). Nanotechnology application in food science and nutrition and its safety issues: A review. *Advances in Bioresources, 11*, 23–35.
10. Mohammad, Z. H., Ahmad, F., Ibrahim, S. A., & Zaidi, S. (2022). Application of nanotechnology in different aspects of the food industry. *Discover Food, 2*, 12. https://doi.org/10.1007/s44187-022-00013-9

Research Trends in Food Science and Technology

ISBN: 978-93-48620-68-2

About Editors

Dr. Ankita Sharma holds an MSc (Hons) in Foods and Nutrition (2000) and a Ph.D. (2005) from MPUAT, Udaipur, with an ICMR Fellowship. She also earned an MSc in Microbiology from KSOU Mysore and qualified for UGC and ICAR NET. With over 15 years of experience in research, teaching, nutrition counseling, and extension services, she has served as Consultant IYCF for UNICEF Jaipur, contributing to state guidelines on infant and child feeding. A member of 15+ professional societies, she has attended 30+ conferences and published 55+ research papers. Her innovations include low glycemic flour and papaya-based foods. She has received multiple awards, including the Achiever Award (2019) and Indira Mahila Shakti Puraskar (2021 & 2023). Currently a KVK Scientist at ICAR-Farm Science Centre, AU Jodhpur, she recently secured a copyright and patent for her food and nutrition technologies.

Athulya Sojan is a dedicated researcher pursuing a PhD in Food Science and Agricultural Chemistry at McGill University, Montreal. Her academic journey began with a Bachelor's degree in Dairy Technology, where she gained expertise in dairy processing, quality assurance, and biochemical aspects of dairy products. To expand her knowledge, she completed an Advanced Diploma in Food Science and Technology at Centennial College, Toronto, focusing on food microbiology, processing, and functional food development. She later completed a Master's in Food Science and Agricultural Chemistry at McGill University and fast-tracked to a PhD. Her research focuses on developing caramel-phenolic compound conjugates to create bioactive food ingredients and innovative caramel products that cater to the rising demand for functional foods. Passionate about food science innovation, she aims to develop products that offer both sensory appeal and therapeutic benefits, contributing to advancements in the functional food industry.

Mrs. Nithiya K. is an Assistant Professor in the Department of Mental Health Nursing at Sri Manakula Vinayagar Nursing College, Puducherry. She holds additional qualifications, including a Diploma in Yoga from the Vethathiri Maharishi Institute and a Kayakalpa Course Certificate. She has completed multiple NPTEL-certified courses on Mental Health, Clinical Psychiatry, Ethics Reviews, and Scientific Writing in Health Research. An active researcher, she has published papers in reputed journals such as the International Journal of Information Research and Review and the Indian Journal of Advanced Nursing. Recognized for her contributions to education, she received the "Best Teacher Award" (2023) and the "Best Professor Award" (2024). She has served as a paper evaluator for Pondicherry University, an internal examiner for UG exams, and a trainer in self-care programs. Dedicated to mental health services, she has provided training and support at Fraternal Life Service Home, Puducherry, since 2013.

Dr. Shrikant Verma is currently working in the Department of Personalized and Molecular Medicine, at Era University, Lucknow, U.P. His area of specialization include Molecular Biology, Infectious Diseases, Genome Analysis, and Pharmacogenomics all culminating in Personalized Medicine. He has more than 4 years of working Research Experience. Dr. Verma was bestowed Young Scientist Award organized by the Indian Society of Personalized Medicine. He is the Life Member of several Scientific Societies. Mr. Verma has published more than 37 Research Papers, Reviews, Books, and several Book Chapters in journals of repute. Currently, he is pursuing translational research taking into consideration recently launched pharmacogenomics approach infusing into modern medical practices, especially in the Indian population, to bring the concept of Personalized Medicine from Laboratory to bed in clinical setup.

Bhumi Publishing

ISBN 978-93-48620-68-2

9 789348 620682