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AFSTI Chennai Newsletter

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FOOD SCIENCE & TECH

- Plant-based Proteins
- Nutrition and Food for Gut & Brain
- Nutri genomics
- AI and Data Analytics in food processing

ASSOCIATION OF FOOD SCIENTISTS & TECHNOLOGISTS (INDIA) - CHENNAI CHAPTER

Food Technology Division, Department of Biotechnology, Anna University, Chennai

AFST(I) – Chennai Chapter Newsletter (April 2025)

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Editorial

Dear Food Professionals,

Greetings from AFST (I) Chennai Chapter!

We are pleased to bring you the April 2025 edition of our AFSTI Chennai chapter newsletter with new articles. This e-newsletter serves as a medium for all of us to get connected and share Food Science and technology-related ideas, experiences, and expertise with each other.

Regarding food product knowledge among consumers, they are gaining more awareness about the different foods and their relation to health through different public sources. They understand the products by reading the package information. It is highly crucial for the customers to gain knowledge about the products and, in turn, the ingredients used and compare different brands of the same products to choose the right healthy products.

Kindly write to us and let us know your feedback on this newsletter. Your Comments and suggestions are always welcome. We are happy to publish articles from you for the welfare of the society, industry and consumers.

Thank you very much!

Warm Regards from,

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Guidelines to the submission of articles for the newsletter

1. Your content must cover technical/scientific subject relevant to food science and technology.
2. The article must be concise, original and written in 800-1200 words or maximum of 2 pages
3. Articles beyond 1200 words or 2 pages will not be considered for publication
4. Brief profile (up to 50 words) of the author/authors must be added in the end of the article along with the author's contact details (email ID and mobile number) and a recent passport size photograph
5. Following details of the author/authors are required to be included in the profile:
   a) Authors' full names followed by current positions/designation and current organization **(mandatory)**
   b) Education background including institution information and year of graduation (type and level of degree received)
   c) Work experience
   d) Current and previous research interests
   e) Memberships of professional societies and awards received (mainly AFSTI)
6. Articles could be of the following types: Original research manuscripts, reviews, comment. However, the contents must be free from plagiarism
7. The articles have to be submitted in the word document format in the Calibri font (12 size)
8. Images and graphics need to be sent (preferably in PNG format and high resolution) as a separate attachment to include in the article
9. References need to be included for any article involving scientific and technical content
10. The views expressed in the articles reflect the author(s) opinions and do not necessarily are the views of the publisher and the editorial board. The published material, editorials and all other content is published in a good faith. Editorial board of the newsletter cannot guarantee and accepts no liability for any loss, conflict of interest or damage of any kind caused by the newsletter and errors and for the accuracy of details made by the authors.

Tech 250

Air Frying

Air frying technology uses a slight change with the convection method, which has introduced new results of near to crispy fried foods in a healthier way. It uses minimum oil and leads to delicious fried food without guilt. It cooks food faster and comparatively consumes less energy. Food is "fried" by superheated air, not hot oil. The only pre-requisite for air frying is the temperature of the air.

The Air fryer works with hot air as in a convection oven, works similarly to the convection setting with a few modifications. Air is circulated by a powerful fan and heating element to quickly cook foods. Due to the power of the fan speed, the food cooks faster. As the inner chamber reaches the required temperature of around 160 to 180 ° C / 320°F, the air will heat the food and make it crisp.

The food that is in the wire basket, or wire mesh allows hot air to circulate. Its small size means that intense heat levels are reached quickly and evenly, promoting fast, uniform browning. Air frying can be healthier than deep-frying since minimal oil is required. The main advantages Of Air Frying include reduction in oil consumption and in turn reduced calories. The little oil and hot air work together to start the Maillard reaction which makes the food delicious.

The air fryer can generate intense heat, additionally it can be used for broiling, baking, roasting and reheating foods. Further air fryer can be used in dehydrating of foods, as it can be in any other dryers like tray or roller dryers, will low temperature from 40 to 70 ° C depending on the type and size of the food.

Although Air frying is a healthier alternative to deep frying, it can still lead to the formation of acrylamide. However, air frying is expected to have reduced amounts of acrylamide compared to deep-frying. Air frying may produce polycyclic aromatic hydrocarbons (PAHs) also. Although air-fried foods are a real boon for the current age, optimizing food intake is essential.

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Myths and Facts

Avoid processed foods to be healthy

Not all processed foods can be viewed equally. Some processed foods are good for you, such as nut butter, frozen fruits, and vegetables. Moreover, milling of cereals and millets, pasteurization of milk and many other processing methods have become part of our life. Ultra processed foods could be avoided or taken minimally.

Multigrain and whole grains are the same.

Multigrain and whole grain are not the same. Whole grains consist of the unrefined grains whose components — the bran, germ and endosperm — are still intact along with all the fiber, vitamins and minerals produced by nature. Whole grains are more nutritious, and consumption is associated with a lower risk of several diseases.

Multigrain foods are made with more than one grain — but none may be whole grains. Because brown bread is often associated with being healthier than white bread, loaves labeled as multigrain may be dyed to appear darker. Most lack nutritional value after the refining process.

Fruits do not contribute to weight gain.

Fruits are a dense source of sugar and calories along with vitamins and minerals. Especially fruits like mango, banana and jackfruit have high sugar content and hence consumption of high-sugar fruits to be consumed minimally.

Brown sugar is healthier than white sugar.

The color of brown sugar comes from residual molasses. Brown sugar is mostly white sugar with some molasses. While molasses contains some vitamins and minerals like potassium and magnesium. Hence restricting brown sugar is also necessary.

Dr. Kavitha Ravichandran
Food Consultant

AFST(I) – Chennai Chapter Events

1. Celebrating Legacy: Sri Burra Raghuramaiah & Sri GCP Rangarao Memorial Lectures at SRMIST

The Department of Food Process Engineering at SRMIST, in collaboration with AFST(I), Chennai Chapter, hosted an engaging session of memorial lectures on December 7, 2024, at Ramachandran Hall, School of Bioengineering, SRMIST, Kattankulathur, with support from Dr. Periyar Selvam, Heading Food Processing Engineering Department and Dr. Nagamaniammai. The event featured the Sri Burra Raghuramaiah Memorial Lecture, where special guests Ms. Swarup Rane, Managing Director of Food Ingredients Speciality Pvt. Ltd., Chennai, spoke fondly about Raghuramaiah sir's contributions to food regulations and his interest in natural food ingredients. Dr. Nilesh S Amritkar, National President of AFST(I) and Managing Director of Envirocare Labs, emphasized the importance of participation in ICFoST and other scientific and networking events within the AFSTI forum.

Mr. Anurag Lodha, Director of Avlaan Pharmaceutical Pvt. Ltd., Chennai, delivered a lecture on "Startup Risk Management." He discussed the critical aspects of managing risks in startups, including identifying potential risks, developing mitigation strategies, and the importance of adaptability and resilience in the face of challenges.

The event also included the Sri GCP Rangarao Memorial Lecture, where Mr. Karthick Shanmuga Sundaram, Founder and CEO of Gusteau Food Pvt. Ltd., Chennai, spoke on "Exploring Nature's Palette: Future of Plant-Based Food Colors." He explored the innovative use of plant-based food colors, their benefits over synthetic alternatives, and future trends in natural food coloring, emphasizing sustainability and health benefits.

Participants included over 70 students from the School of Bioengineering, SRMIST, Kattankulathur, and AFSTI Headquarters Dr. Nilesh Amritkar, President AFST(I), Dr. Naveen Shivanna, Hon. Secretary, AFST(I) and

Chennai Chapter office bearers, including Dr. Usha Antony, Manivvannan A, Dr. Savitha, Ms. Dhanupriya. The dignitaries also took the time to visit the project expo, where they were impressed by the innovative projects showcased by the students. The expo featured a wide range of projects, from food processing and technology to nutrition and product development. The event was a great success, fostering knowledge sharing and networking among participants.

2. Workshop on Nurturing Innovation: Intellectual Property (IP) Strategies in Food Technology and Biotechnology

The one-day workshop on "Nurturing Innovation: Intellectual Property (IP) Strategies in Food Technology and Biotechnology" was an excellent opportunity for attendees. Conducted by the College of Fish Nutrition and Food Technology (TNJFU) - Chennai, in collaboration with the Institute of Fisheries Post Graduate Studies, TNJFU, Chennai, and sponsored by the Cell for IPR Promotion and Management (CIPAM) and the Association of Food Scientists & Technologists (AFST), India, the event took place at TNJFU - IFPGS, Vaniyanchavadi, Chennai. The session began with a special address by Sanu Jacob, who explained the importance of patents in food technology and biotechnology, providing various examples to illustrate his points.

Dr. M. R. Ramasubramaniyan, Executive Director of the National Agro Foundation, elucidated the history and evolution of Intellectual Property Rights (IPR) and discussed how IPR is related to social responsibility and over-exploitation.

Dr. Gomati Padma Thilaga Sivanantham provided in-depth lessons on the ancient Indian approach to IPR, the characteristics and benefits of IPR protection, the objectives of the IPR regime, patents and their criteria, trademarks, copyrights, Geographical Indications, and trade secrets. Dr. K. Sasi Praba taught attendees about the patent process, its requirements, the application processing, the scope of patents in the food industry and biotechnology, and the challenges in patenting.

Dr. Usha Raja Nanthini shared her expertise on Geographical Indications and traditional knowledge in food and biotechnology, discussing various case studies such as the Lough Neagh Eel, Isle of Man Queenies, Scottish salmon, the anchovies of Phu Quoc Island, Vietnam, Bali Amed Salt, and garlic cultivation in Kodaikanal. Dr. Deepa Boppana presented detailed information about the patent drafting and filing procedure, the three statutory pillars of patentability—Novelty, Inventiveness, and Usefulness—along with inventions that are not patentable under Section 3 and Section 4. She also discussed IP commercialization and technology transfer, citing famous court case examples. The interactive panel discussion was highly educational, and the sessions were both interesting and enlightening. The key takeaways of the participants from the workshop are as follows,

- Basic awareness about different Intellectual Property Rights (IPR) such as Patent, Copyrights, Trademarks, Designs and Layouts, Geographical Indications, etc.
- Significance of filling IPR to protect traditional knowledge
- Process of filing and drafting patent
- How to commercialize the IPR after patenting
- Challenges in filing IPR

A total of 121 participants, including UG students, PG students, and Faculty, benefited from the workshop. Among them, 53 participants attended an Intellectual property-related workshop for the first time, and they gained basic awareness of various aspects of IPR such as Patents, Copyrights, Trademarks, Designs and Layouts, Geographical Indications, and protecting traditional knowledge. This will enthuse them to understand these dimensions better and seek ways to protect the scientific innovations they are likely to be making either during their course or later as professionals.


TAMILNADU Dr.J.JAYALALITHAA FISHERIES UNIVERSITY
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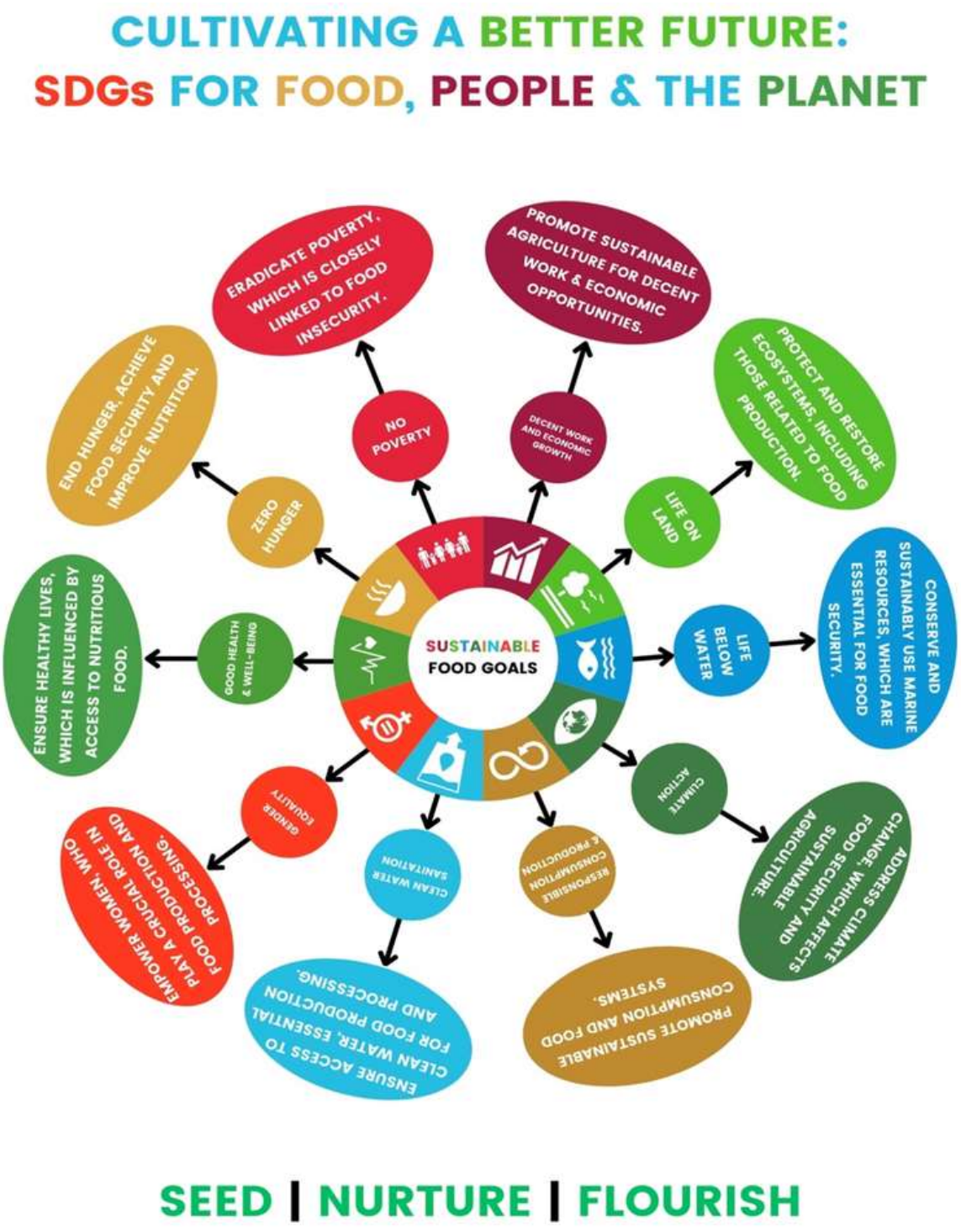
3. Hands-On Workshop on Food Analysis Laboratory

The Department of Home Science, Centre for Nutrition-Counselling, Research and Extension Activities (CNCREA) at Women's Christian College, Chennai, in collaboration with the Association of Food Technologists in India (AFSTI), Chennai Chapter, and the National Food Laboratory (NFL), Chennai, successfully conducted a demonstration cum experiential workshop. The event took place on 24th March 2025 from 10:00 am to 1:00 pm at the Food Analysis Laboratory located on the ground floor of Mason Block at Women's Christian College, Chennai. Food safety officers from the NFL provided the demo and explained the basics, methodology and working principle of the lab analysis equipment including flame photometer, water activity analyser, pH meter, viscometer, penetrometer, consistometer and lactometer.

The workshop was organized by Dr. Sheila John (Associate Professor and Head of PG), Dr. Mary Pramela A (Associate Professor and Head of UG), Dr. Sona S (Associate Professor), and Dr. Suneeta Saghayam (Associate Professor).

The event successfully brought together experts and learners together and provided an opportunity for hands-on learning in food analysis. Expert speakers including Dr. Sanu Jacob ad Dr. Usha Antony highlighted the importance of collaborations between academic institutions, government bodies and professional associations.

Sustainable Food Goals



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Plant Based Proteins and foods

4. Plant-Based Proteins: A Sustainable Solution for the Future

What do we usually understand when we hear the term plant-based protein? We assume it represents the group of pulses, right? Well, I'll not tell that you are completely wrong. Pulses are indeed a source of protein which are obtained from plants. But apart from that, we have legumes, nuts, oats and some seeds which are also some protein rich foods from plants.

First of all, we will see what proteins are and why they are so important. Proteins are large biomolecules, macromolecules, and polypeptide chains consisting of amino acid units bound together by peptide linkages. They exist in different shapes, structures, have different properties like charged/uncharged, acidic/basic, or polar/nonpolar based on the amino acids present.

When we hear the word protein, our thoughts immediately shift towards poultry, beef, meat and most importantly, eggs. Yes, eggs, mainly chicken eggs are the most important source of protein as it is rich in all the essential amino acids required by our body. So, a non-vegetarian is assured of adequate protein intake and utilisation. The same may not be true for a vegetarian diet if not consumed consciously.

The need for plant-based proteins arises due to the following factors:

1) Proteins are the basic building blocks of our body and are made up amino acid units.

2) Some of these amino acids are essential and must be supplied through our diet.

3) It acts as a substitute for meat and other animal protein, thus providing scope for practising vegetarianism and veganism without lacking proteins.

Proteins from soyabean sources are known to be the most effective ones. They prove to be analogues to meat and dairy products not only in texture but also in nutritional content. We have soymilk, tofu – analogue of paneer, tempeh, soy chunks – resembling meat, soy sauce, etc. Plant-based proteins are the only source of proteins in a vegan diet.

Many might have the knowledge of a plant-based protein diet's existence. However, the reason for its need is not merely due to the differing eating patterns. It has a much deeper aspect; one which we might need to start implementing immediately to save our future.

Yes, it is the aspect of sustainability. Usually animal – based products consume a lot of energy and resources than those from plants. Plants- based proteins have a lower carbon footprint than animal – based and thus are better for the environment. Transport, storage and production are also easier if the source is from plant. Land use and water use is also comparatively lesser in plants.

Plant- based protein diet is also cost effective than meat and other products. Moreover, plant foods are less susceptible to diseases and mixing of hazardous and toxic chemicals. Due to the phenomena of biomagnification, the animal products which contain toxic substances, when consumed, cause serious issues to human health. On the other hand, as plants themselves are producers and their products can be directly consumed in a plant-based protein diet, the phenomenon of disease or ill health is prevented to greater extents.

Sustainability has become a very common term in recent days. But to achieve it, one must make some efforts and sacrifices. Also, we should make sure, the real meaning of sustainability is known and understood by all, for the greater good. Thus, it is highly recommended that, considering the advantages of a plant-based protein diet which not only provides adequate nutrition but also has an inherent sustainability factor, even non vegetarians can frequent the intake of plant proteins while minimizing the animal protein.

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5. Single-Cell Protein Extracted from Pineapple Peels

A sustainable way of producing plant-based protein is through Single-Cell Protein (SCP) manufactured from pineapple peels. Single-Cell Proteins (SCP) refer to protein-rich biomass derived from microbial fermentation. They offer a sustainable alternative to conventional protein sources, utilizing microorganisms such as yeast, fungi, and bacteria to convert agricultural waste into high-quality protein *(Umesh et al., 2019; Dharumadurai et al., 2011).* By-products of the fruit processing industry, such as pineapple peels, are ideal for SCP production due to their abundant supply, rich nutrient composition, and ease of microbial degradation.

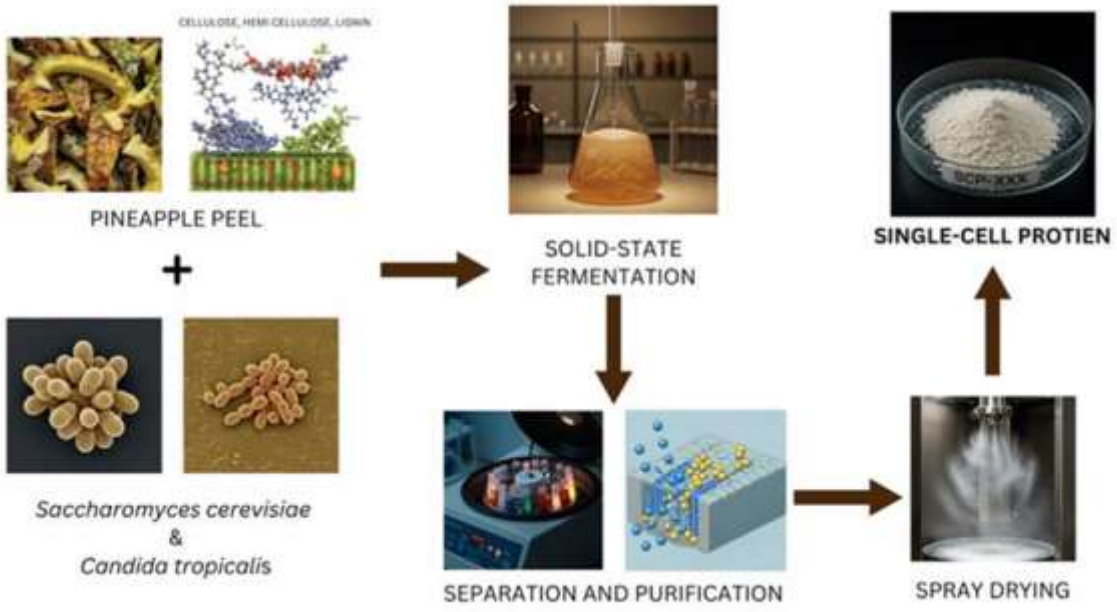
The biochemical composition of pineapple peels includes approximately 25.1% cellulose, 29.3% hemicellulose, 6.3% lignin, and 5.0% ash, making them a rich source of fiber and carbohydrates that support bacterial growth. These peels also contain 10.8% reducing sugars and 13% non-reducing sugars, which serve as fermentable carbon sources for microbial metabolism *(Thiviya et al., 2021; Dorta & Sogi, 2017)*. Their widespread availability ensures a cost-effective and sustainable raw material for large-scale protein production, while their utilization in SCP helps reduce agro-industrial waste and promotes eco-friendly bioconversion. Yeast strains like *Saccharomyces cerevisiae* and *Candida tropicali*s are widely used in fermentation because they can efficiently metabolize the sugars in the peels, thus yielding protein-rich biomass *(Dharumadurai et al., 2011; Umesh et al., 2019)*.

The enzymatic hydrolysis of complex carbohydrates into fermentable sugars plays a significant role in this process, which promotes microbial proliferation and protein synthesis. Production process encompasses the following important stages: substrate pretreatment, microbial inoculation, controlled fermentation, biomass separation, drying and grinding pineapple peels to enhance surface area exposure and microbial access. The set substrate is inoculated under controlled conditions with selected yeast strains. Optimal fermentation parameters include pH, temperature, oxygen levels, and nutrient supplementations to ensure a maximum biomass yield. For example, Yeast growth is favorable at pH 5.0 and 30°C. Fermentation optimum is generally set at between 48 and 72 hours under optimal microbial and environmental conditions *(Ahmed et al., 2024; Abdeen et al., 2024)*.

Supplemental nutrition may be available in Yeast Peptone Dextrose medium for supplemental yeast nutrients. Solid-state fermentation is frequently preferred for SCP production from pineapple peels due to its lower water consumption and cost-effectiveness compared to submerged fermentation *(Ahmed et al., 2024; Abdeen et al., 2024)*. Yeast cultures ferment to multiply, thereby leaving high protein concentration and few undesirable byproducts. As far as microbial strain and efficiency of fermentation are concerned, SCP prepared from pineapple peels generally contains 40% to 60% protein. Filtration and centrifugation are then used to separate the microbial biomass from the remainder substrate. The biomass collected is dried to enhance shelf stability and make it easier to add to food preparations.

Spray drying and freeze-drying are commonly practiced techniques to limit degradation and conserve the nutritional richness of the SCP *(Sekoai et al., 2024)*. The high level of critical amino acids, vitamins, and minerals in SCP make the end powder an effective addition to vegetarian protein foods. Large amounts of leucine, methionine, and lysine amino acids in SCP render it as an effective source of protein substitution in human nutrition *(Sekoai et al., 2024; Koukoumaki et al., 2024)*. Besides its potential for direct human use, SCP has applications in aquaculture, animal feed, and even biodegradable packaging. Several challenges must be addressed to optimize SCP production, including maximizing protein yield, selecting the most efficient microbial strains, and meeting regulatory standards for human consumption. Only based on cost-effective

large-scale bioreactors and practical downstream processing mechanisms can commercial feasibilities be understood.



Research yield efficiency of SCP productivity will enhance through genetic engineering and optimized metabolic pathways, in the way of overexpressing protein biosynthesis genes, knocking out competing pathways, enhancing nutrient uptake, and engineering stress tolerance for higher SCP yield *(Sekoai et al., 2024).* Such SCP can even be further processed with customized fermentation techniques, wherein co-culture with other benevolent micro-organisms or strains of modified yeast with enhanced abilities for protein synthesis can increase their output. Further studies must also be carried out on the digestibility, allergenicity, and bioavailability of SCP derived from pineapple peels for its safety and efficacy as a dietary protein source *(Ahmed et al., 2024)*. It offers new functional applications in food functionality due to other bioactive components like flavonoids and polyphenols which are present within the peels of pineapple fruits. To sum up, SCP made from pineapple peel is a prime example of a novel and sustainable approach to the creation of plant-derived proteins: microbial fermentation for turning agricultural waste into this priceless protein-based resource with a variety of uses.

Further research and technological advancement will be important in maximizing the production process of SCP and thus increase its potential as a substitute mainstream protein supply. The emergent solution of pineapple peel-derived SCP will help meet the global protein needs in the most environmentally sustainable manner to address growing demand for nutritionally rich food sources. With the developments in fermentation technology, process optimization, and obtaining regulatory approvals, SCP from pineapple peels may have a very good chance of being integrated into mainstream food systems, providing a sustainable and environmentally friendly source of protein for the future.

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This paper was guided by Dr. Priyadarshini

6. Sustainable Plant-Based Proteins from Agricultural Wastes

Introduction:

In 2050, there will be 9.7 billion people in the world. Against this background, food production is steadily being driven toward sustainable nutrition 1. Conventional animal protein production is associated with several environmental consequences, including high land and water consumption 2. There has been growing interest in environmentally friendly and nutritionally beneficial protein sources, among which extracts from agricultural waste constitute plant-based proteins that help solve not only the shortage of protein but also environmental sustainability. The development of extraction technologies opened up the potential for protein extraction from agricultural waste even further3.

What is Agricultural Waste?

Agricultural waste refers to by-products that are developed through agriculture and food production. For example, crop residues- the husks, straw, and stems, are products obtained from crops. Crop residues mostly comprise fruit and vegetable peels, seed cakes, among others, and any other items made from plant origins 4. Previously, these wastes were primarily used for low-value purposes such as composting or animal feed. Often, they were left to decompose on farmland, contributing to environmental pollution. However, these by-products are rich in proteins, Fibers, and bioactive compounds, and hence of high value as sources for novel applications. A few of the recent advances in technology, such as pulsed electric field technology, have been considered to enhance protein extraction efficiency 5.

Benefits of Plant-Based Proteins from Agricultural Waste:

Sustainable Impact: These proteins from waste can reduce a company's additional need for more land and water and, by that, a lesser environmental impact of regular proteins. It comes in line more closely with those goals of zero food waste or emissions control 1.

Economic Value: Waste-based agro-products can be converted into value-added proteinaceous materials, increasing farm income and supporting the development of a biobased economy 2.

Nutritional Value: Many plant-based agricultural by-products contain essential amino acids, making them suitable for human nutrition and animal feed. Additionally, these proteins serve as sustainable alternatives to conventional.

Extraction of protein:

1. Enzymatic Hydrolysis: This method uses specific enzymes to help break down plant cell walls so that proteins can be released in their functional state.

2. Chemical Extraction: Acidic or alkaline substances can be used to break down protein, although there is a risk that protein degradation can take place.

3. Physical Methods: To improve protein yields, techniques including high-pressure processing and ultrasound-assisted extraction work to break down the cell structure of plants. PEF technology enhances and increases the efficacy of extraction techniques.

4. Fermentation: This microbial activity enhances farm byproducts' digestibility and protein content. Consequently, new initiatives aimed at enhancing various procedures to produce higher-quality and higher-quantity protein.6 7.

Use of proteins obtained from agricultural waste

Food Industry: They are used in functional foods, healthy supplements, and plant-based meat substitutes. The research demonstrates a variety of roles of these chemicals, accentuating a range of rich plant-derived nutrient diets 1.

Animal Feed: They provide an economical and sustainable protein source to the livestock and fishery animals 2.

Biodegradable Materials: Green bio packaging and edible films are also produced while decreasing plastic waste 8.

Conclusion:

One of the most promising ways to help satisfy the world's protein requirement, with a much lower environmental footprint, is to extract protein from agricultural waste. This enhances the economic health of the agriculture sector, reduces waste, and drives a circular economy. Ongoing progress in extraction technologies and their applications will be the most important drivers for the future of food and agriculture. 12

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7. Lupin: The Future of Plant-Based Protein and Its Sweet Potential in Culinary Innovations

Introduction

As the world moves towards sustainable, plant-based protein sources, lupin is gaining recognition for its exceptional nutrition and versatility. Often overshadowed by soy or pea protein, lupin offers impressive health benefits and a strong protein profile. This article explores lupin's nutritional advantages, its potential in food technology, and our unique experience incorporating it into an innovative cheesecake infused with rose and pomegranate extracts.

The Nutritional Power of Lupin

Lupin beans, from the Lupinus genus, are a top source of plant-based protein, with up to 40% protein content (Bartkiene et al., 2019), surpassing common options like soy and chickpeas. They are also high in dietary fiber, essential amino acids, and bioactive compounds, promoting gut health, weight management, and cardiovascular wellness (Raikos et al., 2014). Unlike soy, lupin is non-allergenic, gluten-free, and has a low glycemic index, making it suitable for those with dietary restrictions. Studies show that lupin flour or protein isolates can help lower cholesterol, improve insulin sensitivity, and support muscle growth (Alu'datt et al., 2014).

Culinary Innovations: Lupin in a Cheesecake?

Our cheesecake was designed to be vegan, gluten-free, protein-rich, cost-effective, and free from artificial sugars, additives, and colors. To make it fully plant-based, we replaced dairy cream cheese with aquafaba and cashew nut paste, ensuring a creamy texture while keeping it nutritious. We used stevia instead of refined sugar, maintaining sweetness without extra calories. The result was a guilt-free, protein-packed cheesecake that combined the richness of lupin with the aromatic infusion of rose and pomegranate extracts.

Sensory Review and Market Potential

The final product received positive feedback, especially for its creamy texture, balanced sweetness, and innovative flavor pairing. Many were impressed by how well lupin complemented the traditional cheesecake while boosting its protein content. The rose and pomegranate extracts added a unique floral-fruity twist, making it stand out in the plant-based dessert market.

With the growing demand for high-protein, plant-based desserts, lupin-based formulations could gain

popularity. Thanks to its neutral taste and excellent binding properties, lupin flour or protein isolates can be used in a variety of baked goods, dairy alternatives, and snacks.

Sustainability and Future Applications

One of the biggest advantages of lupin is its environmental sustainability. Unlike animal-based proteins, lupin requires minimal water, reduces greenhouse gas emissions, and improves soil fertility through nitrogen fixation (Denton et al., 2013). These factors make it an excellent alternative for sustainable food production.

Conclusion

Lupin could be a game-changer in the plant-based protein industry, offering unparalleled health benefits and culinary versatility. Our experience in developing a lupin-based cheesecake highlights its potential in innovative food formulations, proving that nutritious, sustainable, and delicious desserts are possible. With growing consumer interest in protein-rich, eco-friendly foods, lupin is set to redefine the future of plant-based nutrition.

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8. GummiGlow: Fusion of Plant-Powered Nutrition and Irresistible Flavor

Haritaki, or Terminalia chebula, is a revered Ayurvedic herb often called the "King of Medicines" due to its powerful therapeutic properties. This small, greenish fruit is known for its excellent digestive benefits, relieving constipation, promoting gut health, and enhancing nutrient absorption. As a natural detoxifier, Haritaki supports liver function and boosts metabolism while its strong antioxidant and anti-inflammatory properties help improve immunity and reduce oxidative stress. Additionally, it supports brain function and overall vitality. However, excessive consumption may lead to digestive discomfort in sensitive individuals. In contrast, Badam Pisin, derived from almond tree resin, is a plant-based protein source rich in fiber, healthy fats, and essential nutrients like Vitamin E. It aids in gut health, skin hydration, and muscle recovery, making it a valuable addition to a balanced plant-based diet.

An exciting experiment combined Badam Pisin (Almond Gum) and Haritaki Powder (Terminalia chebula) to create homemade gummies. The challenge was to balance the natural bitterness of Haritaki with the mild, gelatinous texture of Badam Pisin while enhancing flavor. To reduce bitterness, Haritaki seeds were soaked in water for five days, then roasted and ground into powder. One cup of water was heated with a quarter spoon of cornstarch and Badam Pisin until thickened, followed by the gradual incorporation of Haritaki powder at varying ratios: 0.2, 0.4, 0.6, 0.8, and 1. Guava juice was added for sweetness and aroma. After refrigerating for an hour, the gummies had a chewy texture and balanced flavor. Sensory analysis showed that the 0.8 ratio of Haritaki powder was the most popular, praised for its mild bitterness, refreshing guava flavor, and pleasant aroma, making it a hit among taste testers.

This experiment with Badam Pisin and Haritaki powder demonstrated how thoughtful preparation can transform a traditionally bitter ingredient into an enjoyable treat. By blending debittered Haritaki seeds with the gelatinous texture of Badam Pisin, gummies were created that offer a pleasant taste and potential health benefits. These gummies can be stored in the refrigerator for up to a month and remain fresh at room temperature for about a week, though optimal flavor is best within seven days. Badam Pisin provides a gentle source of protein, healthy fats, and fiber, while Haritaki Powder adds digestive benefits. Together, these ingredients create a nutritious snack rich in plant-based proteins and essential nutrients.

Haritaki (Terminalia chebula) is renowned for its health benefits, particularly in digestion, detoxification, and immune support. It promotes regular bowel movements, aids liver function, and combats oxidative stress while enhancing immune resilience. Overall, Haritaki is a valuable addition to a holistic wellness regimen.

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9. Heart-Healthy Jams and Squashes with ginger & garlic

Introduction

Heart diseases are among the leading causes of death globally. Ginger and garlic, two commonly used spices in cooking, have been shown to offer potential health benefits in preventing heart disease. This study explores the formulation of jam and squash products using ginger, garlic, honey, and lemon, which are rich in antioxidants, flavonoids, and other bioactive substances that can reduce cardiovascular risk factors. The physicochemical, nutritional, and sensory qualities of these products were assessed, revealing high levels of flavonoids, total phenolic content, and antioxidant activity. Additionally, the products demonstrated enhanced cardiovascular health benefits, such as reducing inflammation, hypertension, and hyperlipidemia. Sensory analysis indicated that consumers appreciated the unique flavor and appearance of the squash and jam.

Objective & Methodology

The objectives of this study were to formulate heart-healthy jam and squash using ginger and garlic, evaluate the sensory attributes of the formulated products, popularize the formulated products among college faculty members, and assess the shelf life of the formulated products.

The key ingredients used in the making of heart-healthy jam and squash include ginger, garlic, lemon, and apple cider vinegar. For the preparation of squash, the process involved selecting samples (ginger, garlic, lemon, apple cider vinegar), sorting, extracting juice (ginger, garlic, lemon), mixing, boiling at a lower temperature, making sugar syrup, adding sugar syrup, cooling, storing in bottles, and refrigeration. For the preparation of jam, the process included selecting samples (ginger, garlic, lemon, apple cider vinegar, honey), sorting, extracting juices (ginger, garlic, lemon), boiling at 100°C, mixing, adding honey, cooling, storing in bottles, and refrigeration.

Summary

The overall acceptability of the product was rated as good (4.5), with specific scores for color (4.4), flavor (4.3), taste (4.7), texture (4.5), and appearance (4.2). The standard deviation was 0.37, and the mean value was 4.02. The shelf-life study revealed that the products could be stored for up to 30 days at room temperature without any effect on their sensory attributes. The study highlights that value-added products can be prepared from certain medicinal herbs. The shelf-life study reveals that the products can be stored for up to 30 days at room temperature without any effect on their sensory attributes. The formulated products received an overall acceptability score of 4.5 and 3.8.

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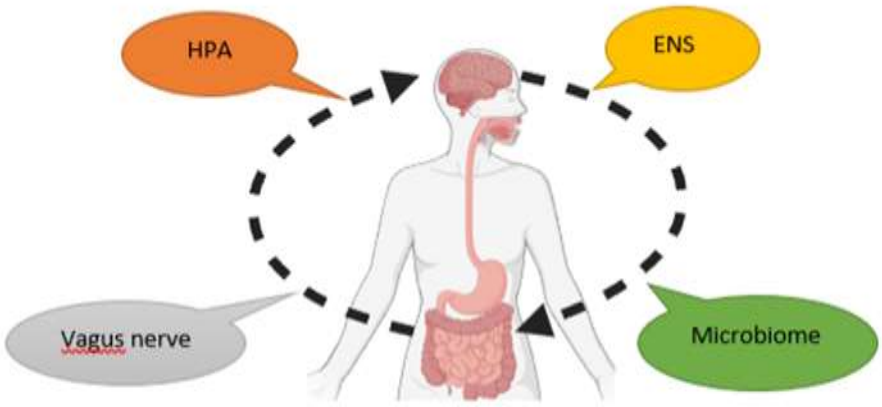
Nutrition and food for gut and brain

10. Insights on the Gut - Brain axis

Gut-brain axis

A bidirectional pathway occurs between the brain and intestine, widely called the gut-brain axis, connects and balances the neural (enteric and central nervous systems), immune system, and hormone signalling 1,2. The vagus nerve is a major autonomic nerve that connects the brain and gastrointestinal system (GI or gut). The gut acts as a sensory organ and also an enteric (autonomic) nervous system. The largest human endocrine organ, enteroendocrine cells in the gut surface have the most nutrient receptors. It is stimulated by both the nutrients from the lumen and metabolites of gut microbiota. Enteroendocrine cell sensing is vital for digestion, the beginning of hormone and neuron changes, and ion transport changes in the gut mucosal layer. For normal gastrointestinal function, this signalling between the brain and gut is so crucial. The human intestine is also a producer of various neural metabolites and neural transmitters (gamma-aminobutyric acid, Serotonin, and other Short-chain fatty acids) which affect the gut-brain axis. The gut microbes are also involved in regulating the intestinal epithelial barrier to prevent the entry of live toxins and bacteria into the bloodstream. This will improve the lipopolysaccharide in the blood and promote inflammation 2.



Where HPA-Hypothalamic-pituitary-adrenal axis includes the hypothalamus, adrenal and pituitary glands; ENS- Enteric nervous system a part of autonomic nervous system that controls the digestions in gut.

Major components of Gut-brain axis

Factors that affect the gut microbiota

Microbes initially colonize our gut at birth and it changes to more diverse, complex, and most stable during adulthood 3. The gut microbiota is influenced by a wide range of factors including lifestyle, age, environment, genetics, medicine intake, mode of delivery at birth, and health status. However, the major factor is diet, which decides the abundance of selective microbes in the gut. These gut microbes decide nutrition absorption, and neurometabolite signalling 2**.** The dietary factors that have positive impacts on the gut microbiota include high amounts of the Mediterranean diet, fruits, vegetables, nuts, prebiotics, Monounsaturated fatty acids (MUFA), Polyunsaturated fatty acids (PUFA), fibers, plant-based proteins, and fermented foods. The consumption of Western diet, saturated fatty acids, sugar, sweeteners, animal-based

proteins, and emulsifiers will negatively affect the gut microbiota 4**.** Though vegan diets are better than vegetarian diets the Mediterranean diet rich in fruits, vegetables, mono, and polyunsaturated fats is the gold standard diet for optimum health 2.

Diseases associated with gut-brain axis interrelationship

Though the exact reasons or the mechanism by which the autism spectrum disorder (AD) was not explored, the abnormal gastrointestinal behaviour, metabolites excretion, gut microbiota composition, permeability of the intestine, and several compounds metabolism like Carbohydrate, amino acids, etc.,) were commonly observed in some groups AD. The *clostridium* spores in surroundings, selective feeding might be a causative factor for AD 5**.** In the case of psychiatric point, studies showed probiotics affected serotonin metabolism and produced an antidepressant effect (*Lactobacillus plantarum*) 1. Obesity (excessive deposits of fats in the body) is globally a major disease. Regular intake of caloric-restricted and plant-based nutrients creates various beneficial changes in the brain like decreased craving for foods and improved structural and functional connectivity, hippocampus volume and the response of the brain response, and also in the gut like improving the short-chain fatty acids, microbiota diversity, neurotrophic factors and precursors of neurotransmitter. While accumulation of visceral fat, malnutrition, and weight gain have shown negative effects on the structure and functions of the brain and gut 6. Apart from diseases, the gut-brain axis showed its influence on the growth retardation in children 7.

Fermented food for improving gut-brain health

Fermented foods have been part of our diet since age old days. These vast food products include dairy to non-dairy products made from milk to different parts of plants and its products, by selective stains of microbes. These fermented foods showed beneficial effects including neuroprotection, improved memory functions, and decreased neurotoxicity, etc., This was suggested due to increased chemical changes like bioactive peptides, phytochemicals, neuroprotective effects, and increased bioavailability 8**.** Fermented foods also showed improved positive mental health with their enhanced nutrients (eg., polyamines and agmatine) and phytochemicals 9. In terms of mechanism, the probiotic organisms promote better gut by improving the commensal intestinal microbiota and cognitive function through several neurochemical modulations including reduction in hippocampal brain-derived neurotrophic factor), alterations in the inhibitory neurotransmitter gamma-aminobutyric acid (*Lactobacillus rhamnosus*), reducing the stress by preventing the hyperactivity of hypothalamic-pituitary-adrenal axis and also changes the turnover of serotonin 8**.** Based on the various reports previously done mostly fermented foods showed an anti-stress or antidepressant or improved the mood of the consumer after the respective period of the experiment 10.

Future directions

Though animal studies results showed the interrelationship between the gut-brain axis, these results are subject to change if done in the human population. More research needs to be done on this specific emerging topic. Also recovering the microbes back by dietary intake and their direct impact on the brain needs to be explored further. More extensive studies need to be done on the disease and its exact inhibition through foods by the gut-brain axis.

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11. Health Aspects and Foods for Gut-Brain Axis

Gut-Brain Axis

The gut is often referred to as the second brain of the body, controlling many physical and mental functions just like the brain in our heads. Together, the gut and brain form the gut-brain axis, an intricate connection between the gastrointestinal system and the central nervous system. This connection has garnered significant attention from researchers and health enthusiasts alike as a key link between modern disease epidemics, from obesity to cardiovascular and mental health. As we continue to uncover the mysteries of the gut-brain axis, one thing is clear: nutrition plays a pivotal role in maintaining and enhancing this connection.

It is a two-way street:

The gut-brain axis is a bidirectional communication system involving the central nervous system (CNS) and the enteric nervous system (ENS). This connection is facilitated by neural, hormonal, and immunological pathways, allowing the gut and brain to influence each other's function. The gut microbiota—trillions of microorganisms residing in the digestive tract—plays a crucial role in this communication, impacting mood, cognition, and overall health. Almost 90 percent of the cells in your body are bacterial cells; only 10 percent are human cells. This ecosystem of microbes in your gut is as diverse as the Amazon rainforest, consisting of thousands of species all with different functions. Your health is incredibly dependent upon the life and vibrancy of this rainforest. Your gut bacteria digest certain foods, produce essential vitamins and hormones, respond to medicine and infections, and control your blood sugar and blood cholesterol levels.

The gut-brain axis plays a vital role in regulating various aspects of health:

• **Mental Health:** The gut microbiota has been linked to mental health conditions such as anxiety, depression, and stress. Imbalances in gut bacteria can influence neurotransmitter production and inflammation, impacting mood and behaviour.

• **Cognitive Function:** A healthy gut can enhance cognitive function and protect against neurodegenerative diseases. The gut microbiota produces metabolites that support brain health and cognitive processes.

• **Digestive Health:** The gut-brain axis plays a vital role in regulating digestion. Stress and emotions can impact gut motility and function, leading to conditions like irritable bowel syndrome (IBS).

Nutrition is the science of how food and drink impact our bodies, providing the essential nutrients we need to maintain good health and support our physiological functions. It encompasses the processes of ingestion, digestion, absorption, metabolism, and excretion of nutrients. Food has a powerful impact on brain function and mental health through various mechanisms. Here's how nutrition can influence your brain and gut:

• **Nutrient Supply:** Essential nutrients like B vitamins, vitamin D, iron, and magnesium are crucial for brain function. Deficiencies can impair cognitive function and mood. Foods rich in antioxidants, such as berries and leafy greens, protect brain cells from oxidative stress and inflammation, supporting overall brain health.

• **Neurotransmitter Production:** Proteins in food are broken down into amino acids, which are the building blocks of neurotransmitters. For example, tryptophan (found in turkey, eggs, and nuts) is a precursor to serotonin, which regulates mood. Consuming carbohydrates increases the production of insulin, which helps the amino acid tryptophan enter the brain, boosting serotonin levels.

• **Energy Supply**: The brain's primary energy source is glucose, derived from carbohydrates. Stable blood sugar levels, maintained through balanced meals, ensure a steady energy supply to the brain. Omega-3 fatty acids, found in fish, flaxseeds, and walnuts, support brain cell structure and function, promoting cognitive health.

• Gut-Brain Connection: The gut microbiome influences brain function through the gut-brain axis. A balanced gut microbiome, supported by probiotics (yogurt, kefir) and prebiotics (garlic, onions), enhances mental health and cognitive function. Foods like sauerkraut, kimchi, and kombucha contain probiotics that support gut health and, in turn, positively impact mood and cognition.

• Inflammation and Immune Function: Diets rich in anti-inflammatory foods, such as turmeric, ginger, and fatty fish, can reduce inflammation in the body and brain, supporting mental health. Omega-3 fatty acids have anti-inflammatory properties and support brain health by reducing inflammation and promoting neurotransmitter function.

• Mood and Cognitive Function: Magnesium, found in leafy greens, nuts, and seeds, plays a role in neurotransmitter function and can help alleviate symptoms of depression and anxiety. Foods like dark chocolate, berries, and green tea contain antioxidants that improve mood and cognitive function by reducing oxidative stress.

Specific foods and practices play a crucial role in supporting the gut-brain axis:

- Probiotics: Yogurt, kefir, and sauerkraut contain live cultures that support a healthy gut microbiome, enhancing gut-brain communication.
- Prebiotics: Garlic, onions, and whole grains nourish beneficial gut bacteria, promoting a healthy gut environment.
- Omega-3 Fatty Acids: Fatty fish, flaxseeds, and walnuts support brain cell structure, reduce inflammation, and enhance cognitive function.
- Antioxidants: Berries, dark chocolate, and spinach protect brain cells from oxidative stress and improve mood and cognitive function.
- Fiber: Fruits, vegetables, and whole grains support digestion and promote a healthy gut microbiome, which in turn influences brain health.
- Hydration: Staying hydrated is essential for maintaining proper digestion and supporting the gut's functions.
- Stress Management: Reducing stress through activities like meditation, yoga, and exercise can positively impact gut health and the gut-brain connection.

Conclusion:

The gut-brain axis underscores the profound connection between our digestive system and mental health. By prioritizing nutrition and incorporating gut-friendly foods into our diets, we can enhance gut health, support brain function, and improve overall well-being. As research on the gut-brain axis continues to evolve, one thing remains certain: nourishing our gut is key to a healthy, happy brain. Understanding and nurturing the gut-brain axis is key to achieving a balanced and healthy life. Whether through probiotics, prebiotics, or nutrient-rich foods, taking care of our gut can lead to a happier and healthier brain.

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12. The Connection Between Gut and Brain Health: Nutrition for Optimal Well-being

The gut-brain axis is a sophisticated communication system that connects the central nervous system and the gastrointestinal tract, establishing a close connection between the gut and brain. This connection is crucial for mood control, mental health, cognitive performance, and overall well-being. Consuming the right foods can improve brain function and gut microbiota balance, leading to better digestion, reduced inflammation, increased mental clarity, and emotional stability. This article explores key nutrients and food choices that promote optimal gut and brain health.

Gut Health: The Foundation of Well-being

The gut microbiome is composed of trillions of bacteria, fungi, and other microorganisms that reside in the gut. These microbes are essential for immune system function, digestion, and even mood management because they produce neurotransmitters like serotonin. Probiotics, prebiotics, fiber, and gut-healing foods are all necessary for a balanced gut microbiome.

Probiotic-Rich Foods: The Good Bacteria

Live beneficial bacteria, or probiotics, support a healthy gut flora, improve digestion, and strengthen the immune system. Regular consumption of foods high in probiotics can enhance gut health and reduce symptoms like inflammation, bloating, and indigestion. Fermented dairy products such as yogurt with live cultures, kefir, and aged cheeses like Gouda, Cheddar, and Swiss aid in digestion and the diversity of gut flora. Fermented vegetables like pickles, kimchi, and sauerkraut offer vital vitamins and fiber while introducing beneficial bacteria into the digestive system. Fermented foods made from soy, such as miso, tempeh, and natto, promote digestion and build the gut lining.

Prebiotic Foods: Fuel for Good Bacteria

Prebiotics are fibers that help the good bacteria in the gut grow and proliferate by providing them with nourishment. Consuming meals high in prebiotics ensures a resilient and well-balanced microbiota. Vegetables like garlic, onions, leeks, asparagus, and Jerusalem artichokes are rich in inulin, a form of prebiotic fiber that promotes intestinal flora. Whole grains such as oats, barley, quinoa, and whole wheat products support the growth of gut bacteria and a healthy digestive system. Legumes like black beans, chickpeas, and lentils provide plant-based protein and other nutrients, including prebiotic fiber. Fruits like bananas, apples, and berries contain pectin, a fiber that supports gut flora and facilitates better digestion.

Gut-Healing Foods: Repairing and Strengthening the Gut Lining

A healthy gut lining is essential to avoid inflammation and ensure adequate nutrient absorption. Some foods support intestinal barrier integrity and healing. Bone broth, packed with collagen, glutamine, and other amino acids, helps heal the lining of the stomach and reduces inflammation. Turmeric and ginger, known for their anti-inflammatory properties, support a healthy gut flora and facilitate digestion. Omega-3 fatty acids, found in walnuts, flaxseeds, and fatty fish like salmon, sardines, and mackerel, lower inflammation in the gut and promote microbial diversity. Licorice root and aloe vera, known for their calming qualities, can enhance digestive health and reduce leaky gut symptoms.

Brain Health: Mind-Nourishing Nutrition

Appropriate nutrition is necessary for a healthy brain to perform at its best. Emotional stability, memory retention, and cognitive function are all improved by nutrients that promote brain health. Neurological function is greatly aided by a diet high in antioxidants, healthy fats, and essential vitamins.

Good Fats: The Components of Brain Cells

Since fat makes up around 60% of the brain, dietary fats are necessary for neurotransmitter activity, brain cell membrane integrity, and cognitive function. Fatty fish like salmon, sardines, and mackerel are rich in DHA, an omega-3 fatty acid essential for brain function. Nuts and seeds such as walnuts, almonds, flaxseeds, and chia seeds are rich in magnesium, vitamin E, and healthy fats, promoting cognitive performance and shielding brain cells from oxidative stress. Extra virgin olive oil and avocados, high in polyphenols and monounsaturated fats, improve brain function and reduce inflammation.

Antioxidants and Foods That Reduce Inflammation: Safeguarding Brain Cells

Neurological diseases and cognitive impairment are exacerbated by oxidative stress and inflammation. Foods high in antioxidants improve brain function and protect neurons. Berries like blueberries, strawberries, and blackberries are packed with antioxidants that enhance memory and cognitive function. Dark leafy greens such as spinach, kale, and Swiss chard contain vitamins K, A, and folate, all necessary for brain function. Dark chocolate, rich in antioxidants, caffeine, and flavonoids, improves mood and cognitive performance.

Crucial Nutrients for Increasing Brain Function

Neurotransmitter synthesis, mood modulation, and brain function are significantly impacted by specific vitamins and minerals. Choline, essential for the synthesis of acetylcholine, a neurotransmitter that promotes memory and learning, is found in egg yolks, liver, and soybeans. Magnesium, found in dark chocolate, almonds, and pumpkin seeds, improves focus, reduces tension, and soothes the nervous system. B vitamins, present in whole grains, eggs, and leafy greens, are crucial for the brain's neurotransmitter system and energy generation.

The Gut-Brain Connection: Foods That Benefit Both

Neurotransmitters, hormones, and immune system signals are the means by which the gut and brain exchange information. Some foods have a beneficial effect on both systems, enhancing overall health. Fermented foods balance the gut microbiota while boosting mood and mental clarity. Good fats promote digestion and cognitive function by reducing inflammation in the brain and gut. Polyphenols, found in berries, dark chocolate, and green tea, support gut flora and safeguard brain cells. Fiber-rich foods help maintain a healthy gut microbiota while controlling stress and mood.

Avoidable Foods for Brain and Gut Health

Certain foods can damage gut flora and cause inflammation, impairing gut and brain health. Processed foods with unhealthy fats, artificial additives, and preservatives can alter the gut microbiota and cause cognitive deterioration. Refined sugars can lead to mood swings, mental fog, and inflammation, disrupting intestinal flora. Excessive caffeine overstimulates the nervous system and disturbs gut health, while alcohol destroys the gut lining and inhibits brain function.

Conclusion

There is a strong link between gut and brain health, and nutrition is essential to preserving their equilibrium. One can improve digestion, cognitive function, and emotional well-being by eating foods high in probiotics,

prebiotics, healthy fats, antioxidants, and essential nutrients. Reducing consumption of refined carbohydrates, processed meals, and excessive alcohol further safeguards the gut-brain axis. A mindful approach to eating promotes a balanced relationship between intestinal health and mental clarity, ensuring overall energy and well-being.

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13. The Hidden Brain: How Your Gut Microbiota Shapes Your Mind and Body

For years, we've believed that our thoughts, emotions, and decisions come solely from our brains. But what if another intelligence was quietly influencing us from within? Trillions of microbes in our gut, our microbiota aren't just passengers; they actively shape our mood, cravings, weight, and even mental health. If half of the cells in our body aren't even human, who or what is really in charge?

The Gut-Brain Connection: A Silent Superhighway

Your gut and brain are constantly communicating through the vagus nerve, an information superhighway that links them. Scientists have found that gut bacteria produce neurotransmitters like serotonin (90% of it is made in the gut!), dopamine, and GABA, directly influencing emotions, stress levels, and cognitive function. The implications are profound: your gut microbiota may play a crucial role in mental health conditions like depression and anxiety.

Microbial Influence: How Bacteria Shape Behaviour, Weight, and Health

The idea that gut bacteria control more than digestion is gaining traction. Consider these groundbreaking findings:

• Personality Shift: Germ-free mice raised in sterile conditions showed anxiety and social deficits. After receiving a normal microbiota transplant, their behaviour changed and they became more social and confident.

• Weight Control: Scientists transplanted gut bacteria from obese mice into lean ones, and the lean mice gained weight. The reverse was also true. Your microbiota may be as influential as diet and exercise in determining body composition.

• Disease and Longevity: Gut microbes regulate immune function, inflammation, and even the risk of neurodegenerative diseases like Parkinson's and Alzheimer's. A balanced microbiome could be the key to a longer, healthier life.

How Modern Life is Destroying Your Gut Health

Despite the incredible power of our gut microbiota, modern lifestyles are systematically dismantling this delicate ecosystem. Processed foods, excessive antibiotics, artificial additives, and overly sanitized environments disrupt the balance of beneficial microbes. Even birth by C-section deprives newborns of essential bacteria they would normally acquire from their mother, potentially affecting their immunity and metabolism for life.

We've been unknowingly waging war on the very microbes that keep us healthy. Have we sacrificed long-term well-being for the convenience of modern living?

Rebuilding Your Microbiome: The Path to Better Health

The good news? You can restore and maintain a healthy gut microbiome through simple lifestyle changes:

• Eat Whole, Fiber-Rich Foods: Your gut bacteria thrive on Fiber from fruits, vegetables, legumes, and whole grains.

• Consume Fermented Foods: Yogurt, kimchi, sauerkraut, and kombucha introduce beneficial probiotics into your system.

• Avoid Unnecessary Antibiotics & Artificial Additives: Overuse of antibiotics can wipe out beneficial bacteria, and processed foods disrupt gut balance.

• Reduce Stress & Get Outside: Chronic stress harms gut bacteria, while exposure to nature helps diversify the microbiome.

Who's Really in Charge?

We are not just human; we are a symbiotic ecosystem. Our microbes shape our emotions, thoughts, and even our actions. The question of free will takes on a whole new dimension, are we making our own decisions, or are we simply carrying out the wishes of our gut microbes?

One thing is clear: take care of them, and they'll take care of you.

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14. The Sweet Trap: How Sugar Takes Over Your Brain

Picture this: a warm, gooey chocolate chip cookie fresh out of the oven or a velvety scoop of salted caramel ice cream. That first bite sends a wave of sweetness across your tongue, and suddenly, you're hooked. But what's really happening in your brain when you indulge in something sugary? Why does it feel so hard to stop?

The Science of Sugar's Allure

Sugar comes in many forms such as glucose, fructose, and sucrose and while it's a quick source of energy, it does far more than just fuel your body. From the moment it hits your taste buds, sugar sets off a chain reaction in your brain. Specialized receptors on your tongue send signals to your brain's reward system, lighting up areas that make you feel good.

At the heart of this process is dopamine, a neurotransmitter often called the "feel-good" chemical. When you eat sugar, your brain releases a surge of dopamine, creating a sense of pleasure and satisfaction. This is the same system that gets activated by addictive substances like nicotine or alcohol. Over time, your brain starts to associate sugar with reward, making you crave it more and more.

Why We Can't Resist Sugar

Our brains are hardwired to seek out high-calorie foods - a survival mechanism from our ancestors who needed energy-dense foods to survive. But in today's world, where sugary snacks are everywhere, this once-helpful trait has turned against us. Instead of helping us survive, it's driving us to overindulge.

When you eat sugar, it spikes your blood glucose levels, prompting your body to release insulin to regulate it. But if you're constantly eating sugary foods, your body can become less sensitive to insulin, and your brain may start ignoring signals that tell you you're full. This can lead to overeating and, over time, increase the risk of health issues like obesity and diabetes.

The Brain's Love for New Flavors

Here's another twist: your brain loves novelty. When you eat the same sweet treat over and over, the dopamine response starts to fade. That's why you might find yourself searching for new desserts or flavour combinations as your brain is chasing that same high. Food companies know this all too well. They craft products with the perfect blend of sugar, fat, and salt to keep you coming back for more.

Is Sugar Addictive?

The comparison between sugar and addictive drugs isn't far off. Both trigger the brain's reward system, creating a cycle of craving and consumption. The more sugar you eat, the more your brain reinforces the behaviour, making it harder to resist. Over time, you might find yourself reaching for sugary snacks not because you're hungry, but because your brain is demanding its next dopamine hit.

How to Break the Cycle

The good news? Sugar isn't the enemy. It's all about balance. Enjoying a sweet treat now and then won't derail your health, but it's important to be mindful of how much and how often you're indulging. Pairing sugary foods with nutrient-rich options, like fruits or nuts, can help satisfy cravings without going overboard. And understanding how sugar affects your brain can empower you to make smarter choices.

So, the next time you're tempted by a sugary snack, take a moment to think: Are you eating it because you truly want it, or is your brain just chasing that fleeting dopamine rush? By staying aware, you can enjoy the sweetness of life without falling into the trap.

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15. Artificial sweeteners and gut health: Exploring the effects

Understanding Artificial sweeteners:

Artificial sweeteners have emerged as popular alternatives to traditional sweeteners, driven by the growing concern over sugar consumption and its associated rise in obesity and metabolic disorders. Despite their widespread use, the safety and health implications of artificial sweeteners remain a topic of debate, with conflicting evidence contributing to uncertainty about their long-term effects. This review synthesizes current scientific evidence regarding the impact of artificial sweeteners on gut microbiota and gastrointestinal health. Additionally, artificial sweeteners have been shown to influence the production of metabolites by gut bacteria, further impacting systemic health. The findings suggest that artificial sweeteners may have complex and sometimes contradictory effects on gut microbiota. While some studies indicate potential benefits, such as reduced caloric intake and weight management, others highlight detrimental effects on microbial balance and metabolic functions. The inconsistent results underscore the need for further research to comprehensively understand the physiological impacts of various artificial sweeteners on human health. Future studies should aim for long-term, well-controlled investigations to clarify these relationships, ensuring evidence-based guidelines for the safe use of artificial sweeteners in diet management. Some types of Artificial sweeteners are Aspartame, Saccharin, Sucralose, Acesulfame K, Neotame, Advantame, Cyclamate.

How artificial sweeteners impact gut health?

Artificial sweeteners can significantly alter gut bacteria composition and function, potentially leading to glucose intolerance and other health issues, although more research is needed to fully understand the effects in humans. Studies suggest that artificial sweeteners, especially non-sugar sweeteners (NSS), can alter the composition and function of the gut microbiome, the community of microorganisms residing in the digestive tract. Artificial sweeteners like saccharin, sucralose, and aspartame alter gut microbiota, reducing beneficial bacteria and promoting harmful ones. This can lead to gut dysbiosis, inflammation, impaired glucose metabolism, and reduced short-chain fatty acid production. Effects vary by dose and individual microbiome. Natural alternatives like stevia may have fewer negative impacts.

Artificial Sweeteners and Gut Health: Exploring the Impact on Microbiota and Glucose Metabolism

Artificial sweeteners like aspartame and sucralose have minimal impact on gut microbiota composition, with no significant changes in bacterial families or short-chain fatty acid production in healthy adults. However, metabolic responses to non-nutritive sweeteners (NNS) vary among individuals. Sucralose and saccharin have been linked to impaired glucose tolerance, while aspartame and stevia show neutral effects. Significant alterations in microbial functions related to metabolism, including glycolysis, fatty acid biosynthesis, and purine metabolism, were observed in individuals who experienced glucose intolerance. Fecal microbiota transplantation (FMT) studies in mice confirmed that gut microbiome alterations contributed to glucose intolerance in highly responsive individuals.

These findings suggest that while artificial sweeteners do not drastically alter gut microbiota composition, they may still influence metabolic health in susceptible individuals. The potential microbiome-driven metabolic shifts highlight the need for personalized dietary recommendations. Some individuals may experience adverse metabolic effects from consuming certain artificial sweeteners, while others remain unaffected. More long-term research is required to assess the sustained impact of NNS on gut health and metabolism. Understanding individual gut microbiota responses will help in developing better dietary

guidelines and ensuring that artificial sweeteners are used safely without unintended metabolic consequences.

Potential Health Implications of Artificial Sweeteners on Gut Health:

Alteration of Gut Microbiota: A study published in Nature found that artificial sweeteners like saccharin, aspartame, and sucralose can alter gut microbiota composition. They reduce beneficial bacteria, such as Lactobacillus and Bifidobacterium, while promoting harmful strains. This imbalance may contribute to digestive issues, weakened immunity, and metabolic disturbances.

Impact on Metabolism and Glucose Regulation: Research from Nature Medicine reported that artificial sweeteners disrupt gut microbiota, leading to impaired glucose metabolism. They may induce insulin resistance and increase the risk of metabolic disorders, even in individuals without pre-existing conditions. This suggests that artificial sweeteners might not be entirely neutral in terms of metabolic health.

Inflammatory Effects and Gut Barrier Integrity: Studies in Frontiers in Microbiology suggest that certain artificial sweeteners can trigger low-grade intestinal inflammation. They may damage the gut lining, leading to conditions such as leaky gut syndrome. This chronic inflammation is linked to digestive disorders like irritable bowel syndrome (IBS) and inflammatory bowel disease (IBD).

Effects on Appetite and Cravings: Artificial sweeteners can influence hunger hormones by disrupting the gut-brain axis. Research indicates that some individuals experience increased cravings for sweet foods after consuming artificial sweeteners, leading to higher overall caloric intake. This paradoxical effect can contribute to weight gain despite the intended calorie reduction.

Maintaining Gut Health - Tips and Recommendations:

Limiting artificial sweetener intake can help prevent microbial imbalances and metabolic issues, making occasional consumption a safer choice. Opting for natural alternatives like stevia, monk fruit, honey, and jaggery reduces potential risks associated with artificial substitutes. Supporting gut microbiota with probiotics from yogurt, kefir, kimchi, and sauerkraut, along with prebiotic-rich foods like garlic, onions, bananas, and oats, helps maintain a healthy gut environment. Increasing fiber intake through fruits, vegetables, whole grains, and legumes promotes gut diversity, aids digestion, and reduces inflammation.

Staying hydrated is essential for gut motility and can prevent digestive discomfort caused by artificial sweeteners while aiding in natural detoxification. Individuals sensitive to these sweeteners should monitor gut reactions such as bloating or gas and adjust their intake accordingly. Following a balanced diet rich in lean proteins, healthy fats, and whole foods supports gut microbiome stability, reducing the likelihood of artificial sweeteners disrupting digestion.

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16. Health benefits of Banana Pseudo stem and Banana Flower

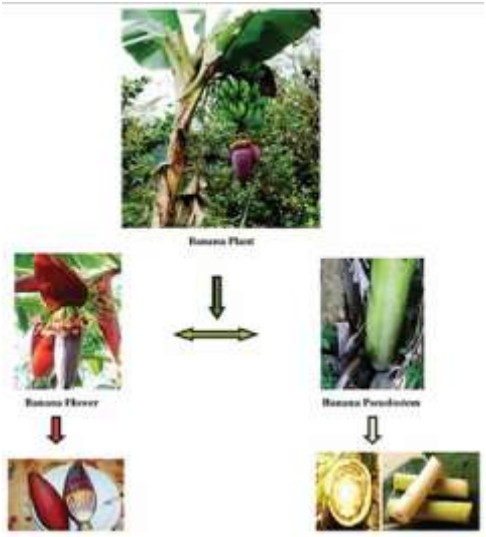
Banana pseudo stem and flower are usually disposed during harvesting [1] due to ignorance of their health benefits. However, they possess a unique blend of nutrients that makes them superfoods for gut and brain. Incorporating them into diet can help reduce the disease burden of India and the epidemic of lifestyle diseases like obesity, heart disease, diabetes and cancer [2].

High Dietary Fibre

Banana flowers contain large proportions of dietary fibre with banana pseudo stem having 61.14% and banana flower having 70.07% respectively, within this they have a large proportion of insoluble fibre (59.10% and 62.93%) [3] This insoluble fibre undergoes fermentation in the small intestine to produce short chain fatty acids like butyric acid.

Colonocytes use butyric acid as an energy substrate. Butyric acid is involved in modulating the growth of intestinal epithelial cells, with benefits in the prevention and treatment of colon cancers. The species of butyrogenic bacteria are *Faecalibacterium prausnitzii* and *Eubacterium rectale*. Butyric acid is an energy source for digestive tract cells. This was evidenced by the comparative measurement of ATP produced by simple colonocytes and colonocytes populated with bacteria specific to the gut microbiome. Unpopulated murine intestinal cells with bacteria had a NADH/NAD + ratio that was 16 times lower than homonymous cells populated with intestinal bacteria. The resulting ATP level was also 56% lower [4].

Butyrate promotes epithelial growth in the colon but, paradoxically, has an inhibitory effect on colorectal cancers. Soluble fibre increases the intestinal volume promoting the feeling of satiety and reduces appetite which could help prevent overeating leading to obesity [4].



High Nutrient Content

Both banana flower and pseudo stem are rich in both macronutrients and micronutrients. Banana flower has 405.50 ppm of iron [3] hence it can be added to diet either in dishes or as functional food to cure anemia and alleviate the deficiency of iron. Banana flower and pseudo stem are rich in Riboflavin, Niacin, Thiamine, β-Carotene Vitamin E, Pyridoxine, and Pantothenic acid which have numerous health benefits like growth of red blood cells, cardiovascular health, hormones and cholesterol production and eyesight.

Banana pseudo stem has relatively low-fat content of 0.98% and hence doesn't add much to body fat [3]. Banana pseudo stem juice also has inhibitory effect on kidney stones due to the presence of inorganic constituents like magnesium, potassium, and nitrate. Magnesium nitrate and potassium nitrate are the major active constituents present in the stem juice, which acts as crystal inhibitors and hence aid in treating and preventing kidney stones. [5]

Furthermore, the ratio of essential to non-essential amino acids in pseudo stem and banana flower is 0.56 and 0.54 which is greater than the FAO recommended ratio of 0.38. However, they are deficient in lysine which is their limiting amino acid.[3] This could be solved by cooking banana pseudo stem and banana flower in the form of curry with lentil and beans that have high lysine content. [7].

Benefits for heart and gut health

Banana flower and pseudo stem have positive effects on cardiovascular health. They have elevated levels of phenols which attenuate the expression of metalloproteinase 1 and reduce plaque accumulation on artery wall [6].

Both banana pseudo stem and banana flower are high in antioxidants, and they are really high in polyphenols [3]. p-hydroxybenzoic acid was the most predominant phenolic acid recorded in PB and FB (62.7 µg/mg and 95 µg/mg) [3]. p-Hydroxybenzoic acid has been shown to alleviate DSS-induced intestinal colitis in rats. p-Hydroxybenzoic acid significantly downregulated the expression of TNF-α and IL-6 at the protein and mRNA levels in a dose-dependent manner, activated ERβ signaling and improved the colon length, this is a promising sign and shows that banana pseudo stem and banana flower might ameorilate intestinal colitis.[8].

Benefits for diabetes:

Banana flower and pseudostem have low GI of just 10.3 and 21.2 making them diabetic friendly [9]. They have anti-diabetic and anti-AGEs properties and are beneficial as food supplements for diabetics. They have been shown to reduce the glomerular filtration rates in diabetic rats, the fasting blood sugar was reduced by 39.8% and 38.5% in banana flower- and pseudostem-fed groups,[9] this is due to the Inhibition of α-amylase and α-glucosidase which reduces the speed of digestion of sugars [10]. Apart from controlling diabetes this also reduces weight gain which is helpful in combating obesity.

Benefits for brain health:

Banana pseudo stem and banana flower are also beneficial for brain health. Both banana flower and pseudostem contain large amounts of tannins (86.87±2.43 and 07.86±0.21 mg/100g) which have anti-inflammatory, anti-Alzheimer, antitumor, and antioxidative properties. Tannins effectively deplete the expression of cytokine markers.[11]

Banana pseudo stem has elevated levels of quercetin which could potentially inhibit mitochondrial dysfunction/oxidative stress induced by oxaliplatin and protect the brain from aluminum induced oxidative damage. [11].

Implementation into diet:

There are many ways in which we can incorporate banana stem and flower into our diet. The flower can be fried and served separately, incorporated into curries or used as the functional component of supplements. The stem can be cooked and eaten with Nutri-cereals; we can also drink the juice of stem. We could also make banana pseudostem powder and use it for fortification or incorporate it into rice and wheat flour. [12] Through these means we can effectively incorporate banana pseudostem and banana flower into our diet.

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AI and Data Analytics in Processed Food Industry

17. Advancing Food Processing with AI: Technological Innovations, Benefits and Challenges

1. Introduction

By 2050, the global population will be steeply increased which led to a huge demand for food up to 59% to 98% (Elferink & Schierhorn, 2016). To meet this demand, a huge human workforce is needed in production, packaging, and quality assurance. But all these procedures, which depend on the human workforce can be time-consuming, might deliver errors, and more often require experienced professionals' input for decision-making in ensuring food safety and quality assessment. To handle these issues, artificial intelligence (AI) has been introduced into various subfields of the food industry, such as streaming supply chains, product sorting, improving quality assessment, and ensuring hygiene (Garver, 2018; Utermohlen, 2019). The main advantage of using AI is it allows for the rapid processing of large volumes of complex data, which further boosts efficiency and accuracy (Othman et al., 2023). AI is applied in analyzing data from sensors, machines, and smart devices, resulting in efficient production, reduced costs, improved food quality, and ensured hygiene. (Ramirez-Asis et al., 2022).

In 2024, the AI market has exceeded $184 billion and by 2030, it is expected to increase $826 billion (Statista, 2024). AI is generally defined as technology that mimics human reasoning, judgment, and decision-making (West & Jhon, 2018). Food Industries experience major hurdles such as food waste, inefficiencies in the supply chain, and issues in food quality and safety. In these areas application of AI helps in predictive analysis and real-time problem-solving through intelligent automation, data analytics, and smart computing, which further allows the industries to operate more productively (Shubhendu & Vijay, 2013).

2. Overview of AI

AI works on three principles such as a) Automation, b) Intelligence, and c) Smart Computing. Reducing the need for human involvement is known as Automation, and extracting valuable insights from the data is known as intelligence, and self-monitoring and reporting is known as Smart computing. AI enhances efficiency and adaptability by mimicking human cognitive functions which is classified into 5 types: Analytical AI, which recognizes the patterns for decision-making (e.g., risk assessment); Functional AI, which we see in robotics and IoT where the tasks are automated; Interactive AI, which allows human-machine communication (e.g., chatbots); Textual AI, which means it processes language for translation and speech recognition; and Visual AI, which explains images and videos for applications like facial recognition and food quality assessment (Sarker, 2022). AI applications can also be classified into two: a) rule-based AI and b) data-driven AI. Rule-based AI works on establishing rules based on an expert's knowledge but has drawbacks in adaptability, while data-driven AI learns continuously from new data to strengthen decision-making (Fig. 1). Some systems, like SPIDER, combine both methods to support food safety management systems such as HACCP (Qian et al., 2023).

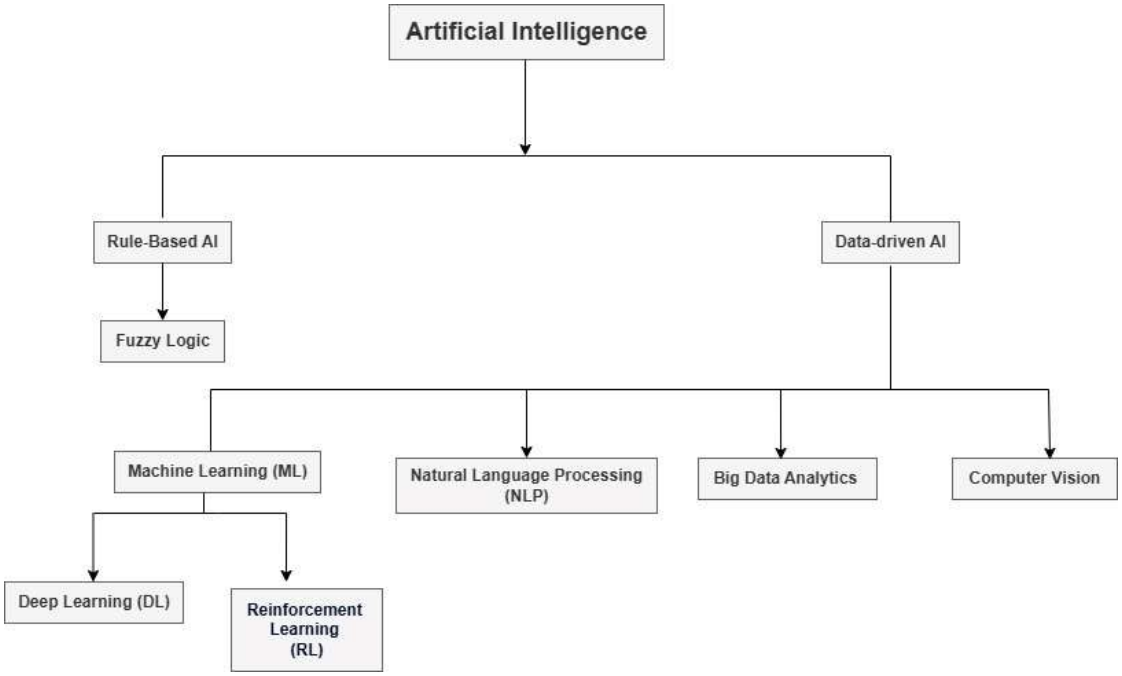

Figure 1. A schematic representation of Artificial Intelligence and its techniques.

3. AI Applications in Food Processing Units

AI techniques such as machine learning (ML), deep learning (DL), big data analytics, natural language processing (NLP), and computer vision (CV) are extensively utilized in food processing (Dhal & Kar, 2025) In this article we will delve into application of Machine learning, Fuzzy logic and Computer Vision in Food Processing facilities (Fig. 2).

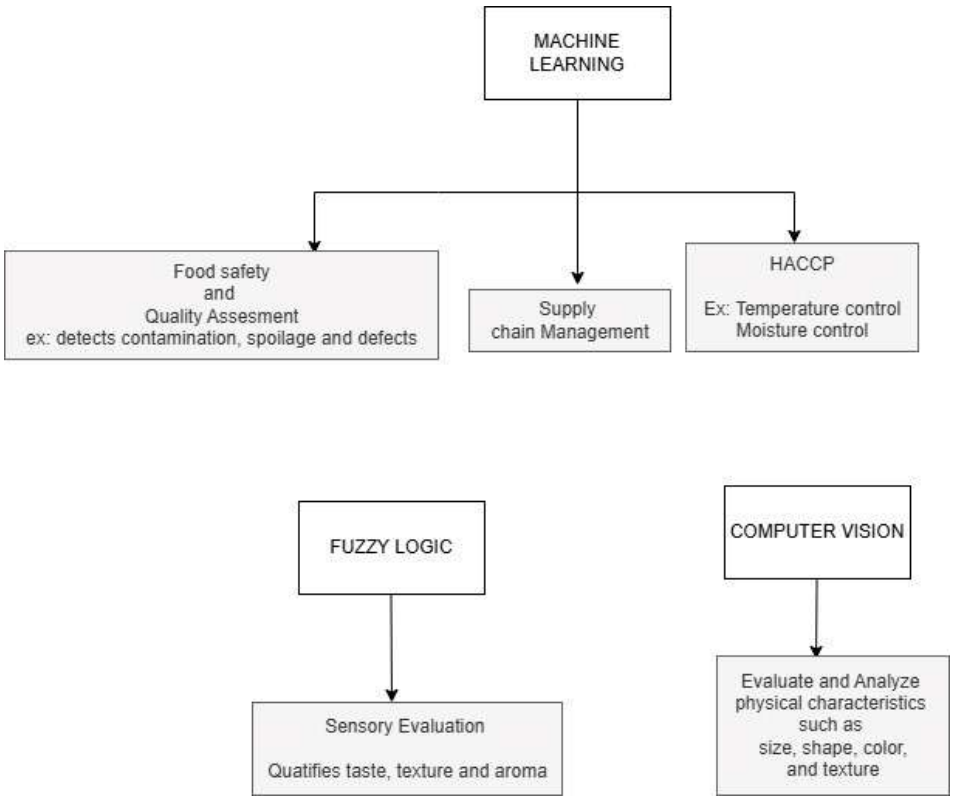

Figure 2. A brief explanation of applications of AI techniques in Food processing units.

3.1. Machine learning (ML) is defined as a subset of AI that allows machines to learn from the data provided without the need for precise programming. The machine learning is categorized into deep learning and reinforcement learning. Machine Learning is mainly used in ensuring food quality and safety, where AI-driven sensors can identify issues like contamination, spoilage, and defects. For example, AI can detect bruised apples or contaminated milk before they reach consumers. ML is used extensively in supply chain management, where it helps forecast demand, which minimizes waste, and maintains optimal stock levels. Additionally, AI systems monitor and adjust important factors like temperature, moisture, and other conditions during food processing which further delivers food quality and safety, while AI predicts potential failures before they happen by analysing the data from the machines in food production units (Ramirez-Asis et al., 2022).

3.2. Fuzzy logic (FL) is another principle of AI technique, which plays an important role in sensory evaluation by handling the subjectivity inherent in human perception. It quantifies sensory attributes such as taste, texture, and aroma, yielding more precise insights into food quality and consumer preferences. This valuable information will be used in product development and quality control (Vivek et al., 2020).

3.3. Computer vision (CV) is another technique that is used in the food industry to promote automated analysis of physical characteristics such as size, shape, colour, and texture. Analysing these physical characteristics delivers quality control, classification, and standardization which enhances productivity in commercial trading and consumer awareness. Examples include detecting defects in fruits, sorting out the potatoes according to the baking conditions, and measuring browning in chips. CV also helps in assessing the degree of ripeness in fruits and vegetables, grading meat, and identifying adulteration. All these examples define that CV is a rapid, cost-effective, and non-invasive method that is applied in food industries which eventually improves food quality assessment without depending on human experience which is time-consuming, and chances of delivering inaccurate results. (Rafiq et al., 2013).

4. Challenges and Limitations

The use of AI has many advantages but has challenges too. Challenges such as limited data sharing, high cost to implement the setup, privacy issues security threats, and possible biases encountered by the food processing and safety units. To overcome these challenges encrypted data-sharing without sharing the sensitive content ensures privacy, using robust security systems, thus enhancing cybersecurity, maintaining standardized data formats, incorporating clear guidelines, and ensuring transparency about how our AI works are crucial. To further AI in food processing, it is important to focus on collaboration, optimized algorithms, sensor fusion, and scalable technology. Implementing changes in phases and assessing return on investment can help alleviate economic challenges and enhance AI adoption (Qian et al., 2023; Mohd Ali et al., 2023; Dhal et al., 2025).

5. Conclusion

In brief, AI is a boon in the food processing sector by improving food safety, quality assessment, and enhancing productivity. Application of techniques such as machine learning, computer vision, and fuzzy logic, AI facilitates detailed monitoring, automation, and predictive decision-making, which reduces human error and enhances productivity. The machines with the integration of AI lead to better food quality, less waste, and more efficient supply chains, promoting a more sustainable food ecosystem. However, it is important to address data privacy, cost challenges, and algorithmic biases through regulatory measures, enhanced security, and workforce training. As AI technology progresses, continuous research and collaboration within

the industry will be essential to fully harness its potential for safer and more efficient progress in the food industry.

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18. AI and Data Analytics in the Processed Food Industry

Introduction

The emergence of data analytics and artificial intelligence (AI) has significantly changed the processed food sector. The development, production, distribution, and marketing of food products have all been completely transformed by this innovative technology. Businesses can increase productivity, boost product quality, guarantee safety, and satisfy changing customer demands by utilizing AI and data analytics. This article discusses the advantages of artificial intelligence (AI) and data analytics in the processed food sector as well as the ensuing difficulties (1,2,3).

What is AI and Data Analytics in the Processed Food Industry?

The term artificial intelligence (AI) describes the replication of human intelligence in machines that are designed to carry out tasks like learning, thinking, and problem-solving. In contrast, data analytics entails analysing huge datasets in order to draw insightful conclusions, spot trends, and aid in decision-making. Applications of artificial intelligence (AI) and data analytics in the processed food sector include:

1. **Product Development:** Predicting consumer preferences and creating innovative recipes (3).

2. **Quality Control:** Detecting anomalies in production processes and ensuring consistent quality.

3. **Supply Chain Optimization:** Streamlining logistics and inventory management (1,3).

4. **Personalized Marketing:** Targeting consumers with tailored promotions and recommendations (4).

5. **Food Safety:** Monitoring contamination risks and ensuring regulatory compliance (5).

Benefits of AI and Data Analytics in the Processed Food Industry

There are several advantages to combining AI and data analytics, including:

1. **Enhanced Efficiency:** Automated processes reduce human intervention, minimize errors, and increase production speed. AI-powered robots, for instance, are capable of accurately doing repetitive jobs like sorting and packaging (1).

2. **Better Product Innovation:** Businesses can spot trends and create goods that meet consumer needs by evaluating consumer data. New food items can be prototyped more quickly thanks to AI algorithms that can mimic flavour and feel (5,6).

3. **Cost Reduction:** By minimising waste and optimising the use of raw materials, predictive analytics helps to cut costs. Furthermore, precise production planning is ensured by AI-driven demand forecasting. With reduced cost, sustainable development goal 2- zero hunger might also be achieved after a long-term application of AI and data analytics in processed food industries (2).

4. **Improved Food Safety:** AI-powered real-time production line monitoring guarantees the early identification of impurities or flaws. Potential hazards can be predicted using machine learning models (5).

5. **Sustainability:** AI can help achieve sustainability goals by optimising the use of water and energy in manufacturing processes (sustainable development goals 6 and 12 can be achieved). Finding sustainable packaging options is an additional benefit of data analytics (1).

6. **Customer Satisfaction:** Targeted marketing initiatives and tailored product recommendations enhance customer satisfaction and increase brand loyalty.

Upcoming Challenges

Despite its several benefits, the adoption of AI and data analytics in the processed food industry is not devoid of challenges. These include:

1. **High Initial Investment:** Implementing AI-driven systems requires substantial financial resources, which may deter small and medium-sized enterprises (SMEs).

2. **Data Privacy Concerns:** Collecting and analysing consumer data raises ethical and legal issues related to data protection and privacy.

3. **Skill Gap**: The industry faces a shortage of skilled professionals who can design, implement, and manage AI and data analytics systems.

4. **Integration Complexities**: Integrating AI tools with existing infrastructure can be a complex and time-consuming process.

5. **Bias in AI Models**: AI algorithms may exhibit biases if trained on unrepresentative or flawed datasets, leading to inaccurate predictions or unfair practices.

6. **Regulatory Challenges**: Navigating the regulatory landscape for AI applications in food safety and labelling can be daunting for businesses.

Conclusion

Through fostering innovation, increasing productivity, and advancing sustainability, artificial intelligence (AI) and data analytics have transformed the processed food sector. By analysing consumer preferences, optimising production, and customised products, these technologies help businesses meet dietary requirements and accelerate innovation.

AI improves operational efficiency by assuring consistent quality, reducing waste, and optimising supply chains. While forecasting demand and logistics optimisation reduce costs and guarantee on-time delivery, predictive solutions reduce equipment downtime.

In sustainability, AI helps reduce food waste, optimize resource use, and recommend eco-friendly practices, advancing the industry's environmental goals.

Nonetheless, issues including skill shortages, high start-up costs, data security, and regulatory compliance need to be resolved. To get beyond these obstacles, cooperation between stakeholders, legislators, and technology suppliers is crucial.

However, challenges like data security, high initial costs, skill gaps, and regulatory compliance must be addressed. Collaboration between technology providers, policymakers, and stakeholders is essential to overcome these barriers.

By leveraging AI and data analytics effectively, the processed food industry can unlock smarter, safer, and more sustainable solutions, paving the way for a transformative future.

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19. Qualitative Fuzzy Logic – Application in Sensory Evaluation of Foods

Manufacturers of Processed foods rely on consumer feedback for product development. Products undergo a 'consumer acceptability test' by Tasters who rank the samples on the attributes (colour, flavour, taste, texture, acidity, crunchiness, etc) according to their liking and preference levels. The technique used is called 'rank rating' and ranks as, 1: dislike extremely; 2: dislike very much; 3: dislike moderately; 4: dislike slightly; 5: neither like nor dislike; 6: like slightly; 7: like moderately, 8: like very much; 9: like extremely (Priulli et al., 2022). Since sensory analysis is fundamentally a descriptive process, the data can be considered more-fuzzy-than-crisp. Moreover, many times consumer opinions are often vague (e.g., "too sweet," "not spicy enough"), thereby making 'quantification of sensory responses', a necessity. It can be comprehended that sensory scores typically force a fixed numerical value on what is often a fuzzy, subjective experience. Fuzzy logic helps manage the inherent subjectivity and vagueness of sensory perceptions. For example, in beverage formulation, fuzzy logic can balance sweetness, acidity, and carbonation to create a product that meets the widest range of consumer preference.

Fuzzy logic uses membership functions to represent the degree to which a product exhibits certain attributes (e.g., "slightly sweet" or "very crunchy"), aligning more closely with how consumers perceive products. Qualitative comparative analysis (QCA) is a research method used to systematically compare multiple cases to understand the conditions under which outcomes occur. Fuzzy Set Qualitative Comparative Analysis (fs/QCA) is an advanced method within the broader QCA approach, integrating the principles of fuzzy set theory with comparative analysis techniques. For example, a 'chip' can be '0.6 acceptable' instead of being simply acceptable (1) or unacceptable (0). The Windows version of the fs/QCA software can be downloaded from the internet (https://sites.socsci.uci.edu/~cra gin/fsQCA/software.shtml) (Ragin & Davey, 2022).

Unlike the classical sets of Set Theory where an element either belongs to a set or does not (binary membership: 0 or 1), fuzzy sets allow for partial membership. Each panellist with his/her set of scores is referred to as 'case.' Fuzzification of this data can be achieved by segregating them into sets where each datum gets a sense of belonging (to a set). This partial membership is quantified using a membership function, which assigns a score between 0 and 1 to each element. For a study with an Outcome as 'acceptable' (1) or 'unacceptable' (0), a 6-value 'Membership Function' (MF) can segregate the data into the sets – where 1 = fully in, 0.8 = mostly in, 0.6 = more in than out, 0.4 = more out than in, and 0.2 = mostly out, 0 = fully out. The criteria for classifying an acceptable score (1–9) to one of the six values can be created based on prior knowledge of the field, and there is no need to separate the score evenly. The scores reflect the varying degrees to which different cases belong to a set.

The detailed procedure on treating the sensory data to convert them into fuzzy data scores is published in the authors' recent publication (Pallavi, 2025). At the end of the process, we can conclude to what varying degrees each attribute of the product is in one way or other responsible for accepting and rejecting it. Additionally, out of all the attributes and their combinations, it could be possible that there is a subset of conditions that are in fact 'enough' to cause an Outcome (product acceptability) irrespective of the presence or absence of the rest of the condition (s) within a set. Therefore, we can identify a 'Necessary Condition' which is required for product acceptability; that cannot be replaced by something else. Based on sensory score data, fs/QCA can identify a 'Parsimonious Solution' that will identify the single most important attribute responsible for product acceptability. At the same time, it can also identify the single most important

attribute that is responsible for low sensory scores leading to product rejection amongst majority of the panellists.

At this point an academic reader may contemplate that to analyse datasets, a method like Principal Component Analysis (PCA) should suffice to identify which of the individual independent variables is responsible for a dependent Outcome. However, this method can only present the data as individual components and arrange them in an ascending order of influence over the dependent variable. Interestingly, the fs/QCA interface can do more, as it is aimed to identify 'between variable' relationships too. Conditions are evaluated individually and in combination – within-case and between-case using Boolean logic (and/or/not).

In summary, fuzzy logic provides a more adaptable and realistic framework for describing products by embracing the uncertainty and nuance of sensory data, whereas traditional sensory scores often oversimplify complex sensory experiences. The fs/QCA approach enables the early identification of the key factors that drive consumer acceptance during the food formulation and calibration stages. As a result, it allows for a clear ranking of how different conditions influence the outcome, lowering rejection costs. Therefore, by using fuzzy inference systems, manufacturers can set more robust control limits and decision rules, making it easier to maintain product consistency even when the raw sensory data are imprecise.

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20. Innovations In Quality, Detection and Sensing Systems in Dairy and Food Sector

Introduction

Food quality, safety and authenticity are important issues that have attracted much attention in the last decade from the industry, the scientific community and consumers. Ensuring safety and security of the global food supply chain, is crucial for public health, economic stability, and environmental sustainability. The complex worldwide distribution and varied processing methods, used in modern food systems, demand advanced solutions for detecting and quantifying contaminants and maintaining food quality.

Traditional analytical methods used in food are characterized by several challenges, encouraging the development of novel tools and instruments. Moreover, the outbreak of the COVID-19 pandemic has highlighted the need for the development of analytical techniques that minimise human contact with food products. The techniques developed should be adept at identifying a broad range of food borne pathogens, chemical contaminants, and adulterants while monitoring food freshness and quality. Recent innovations include multiple materials and methods (non-destructive) that provide miniaturized, portable devices for on-site and real-time analysis. Sensitivity, selectivity, and matrix effects, along with regulatory and standardization issues are challenges that need to be addressed. Packaging technologies that can monitor the conditions of packaged foods, provide real-time information about the quality of foods and offer dynamic expiry dates are being developed. The transition from fixed shelf life to dynamic shelf life reduces food waste and offers protection to consumers from food borne hazards.

Different innovative processing, and preservation techniques, and analytical methodological approaches have been developed to meet environmental challenges and consumer demand for food of high quality and sustainable production supported by circular economy principles. This development has been enhanced and increased during the ongoing age of the fourth industrial revolution (Industry 4.0), which has been gaining momentum since 2015, coming up with a range of automated and digitized technologies. The convergence and interaction of biological, physical, and digital worlds in which automation, digitalization, and networking play a crucial role in the development of these technologies. The major technology clusters that are more relevant to the food industry are Artificial Intelligence (AI), smart sensors, autonomous robotics, the Internet of Things (IoT), big data, blockchain, additive technologies, and advanced nano-biotechnology, among others. These technologies have enabled custom mass production with increased productivity, flexibility, and efficiency. Emerging technologies, such as pulsed electric field, high-pressure processing, ohmic heating, modified atmosphere packaging, cold plasma, nanotechnology, advanced mass spectrometry and hyperspectral imaging sensors are among the key elements in the current food revolution. Several studies have shown that such preservation methods are energy-efficient and allow for the inactivation of microbes and enzyme activity in food items while maintaining sensory quality characteristics.

This has opened several possibilities in the food industry. For example, advancement in several spectral fingerprinting techniques, are used for online measurement of composition and quality predictions, safety, and authenticity of muscle foods. The development of portable and hand-held devices has emerged due to significant miniaturization of spectral techniques. Moreover, smartphones are increasingly used as promising biosensors for non-invasive, portable food quality assessment. Another example of technologies that have boomed in the age of Industry 4.0 is additive manufacturing or 3D printing. Although it is still at the conceptual stage, 3D food printing offers numerous possibilities for the development of tailored animal protein-based products, such as meat and other muscle food products and plant-based vegan alternates.

Aspects related to innovations in quality detection and sensing systems in the food and dairy sector are discussed below.

Quality, Detection and Sensing Systems:

1. Innovation in Imaging Techniques

Multispectral imaging (MSI) coupled with artificial intelligence (AI), machine-learning (ML), and signal-processing techniques may serve as testing tools in food quality control. Most of the recent research has been focused on reflectance MSI, but a system with both reflectance and transmittance capabilities would be ideal for a wide array of specimen types including solid and liquid samples. An innovative merged mode in which both reflectance and transmittance information of a specimen are combined to form a higher-dimensional dataset with more features to analyze spatial and temporal variations of measurements can ensure the quality of measurements. Specific case studies food samples such as turmeric powder and coconut oil proved the validity of the technique. The classification accuracy of standard colour palette testing was over 90% and the accuracy of coconut oil adulteration was over 95%. The merged mode was able to provide the best accuracy of 99% for the turmeric adulteration and linear functional mapping of coconut oil adulteration gave an R2 value of 0.9558 (Udayaganga et al, 2024).

1.1 Spectroscopic and hyperspectral sensors

Simple and rapid measurements with or without sample contact in the specific fringe of the electromagnetic spectrum, Vis (Visible), UV (Ultraviolet), MIR (Mid-infrared), NIR (near infrared), Raman, and fluorescence have been developed over the years. Each spectral range is associated with specific chemical and physical information about the molecular content of the studied sample. For example, the NIR (780–2,500 nm) and MIR (2,500–25,000 nm) infrared ranges are associated with the absorption spectrum of organic molecules with fundamental vibrations observed in the MIR and combinations/overtones vibrations observed in the NIR range, respectively. Raman spectroscopy is based on the inelastic scattering of light observed after radiation with monochromatic light of an organic molecule. Fluorescence can be considered as the emission of lower energy light by a fluorophore after excitation by UV (200– 400 nm) or Vis (400–700 nm) light. Hyperspectral imaging (HSI), also called chemical or spectral imaging, can be considered one of the most recent and disruptive innovations or development in the field of spectroscopy sensors. Food products, especially muscle foods are generally anisotropic and can have high local heterogeneity in physical properties (e.g. size and shape) and chemical composition (e.g., fat, protein, and collagen) making it challenging to control and optimize the quality of final food product.

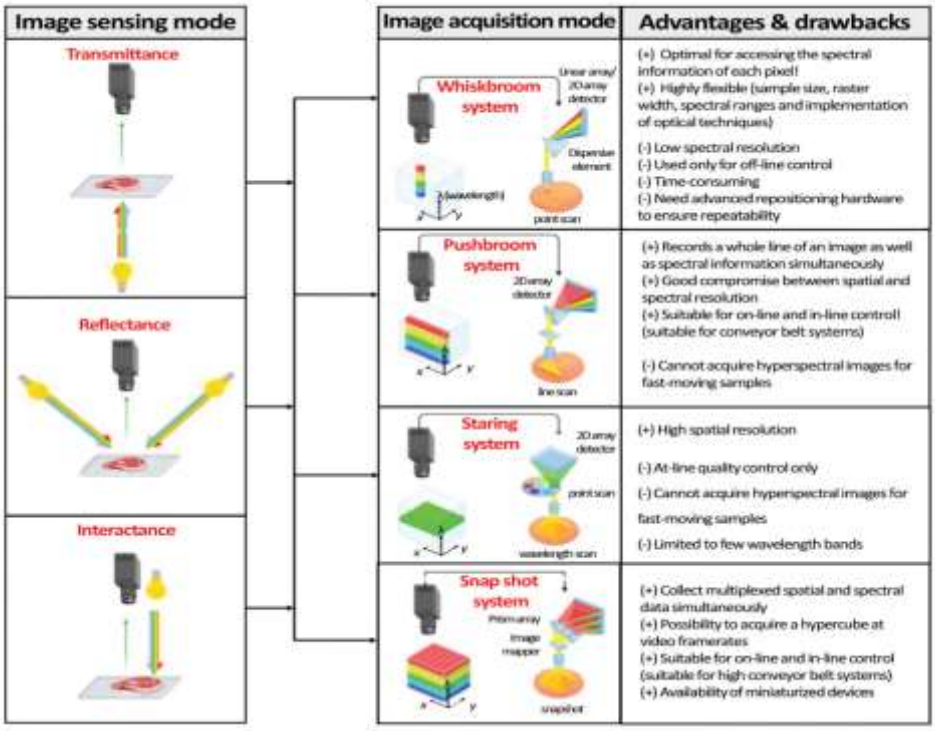

Fig. 1 Different sensing and image acquisition modes that can be used for muscle foods analysis by hyperspectral imaging (Hassoun et al, 2024)

The HSI technique is very smart since it gives the possibility to both record spectral and spatial information of the analysed sample. The HSI data analysis is generally associated with multivariate or chemometrics techniques (e.g., principal components analysis, partial least squares analysis and artificial neural network) to build predictive models or to visualize quality variations based on distribution maps of muscle food products (e.g., fish, chicken, red meats). The HSI sensor generally contains four elements, including a “brain” (a computer with appropriate software), a sample stage, a “vision” system (CDD hyperspectral camera), and an illumination source (e.g. tungsten-halogen, UV lamp). The illumination source should be chosen carefully depending on the application, to provide illumination homogeneity and prevent heating effects. The HSI sensors can provide images using three configurations: reflection, transmission, and interactance (Fig 1). In general, in muscle product analysis, the reflectance mode is the most used probably because it is the most convenient and informative.

The most recent HSI sensors are called single shot or snapshot HSI. These sensors are capable to record both spatial and spectral information in all the object area in one shot without scanning. This system provides advantages such as collecting HSI images at video frame rate making the sensors more appropriate for real-time applications, ultra-portability or miniaturization. The application of these techniques could discriminate between three red meat species (pork, beef, and lamb). Smart sensors based on HSI, and spectroscopy can enhance food traceability and can help the food industry to move to the next level by enabling real-time monitoring and reducing measurement time.

Ambient mass spectrometry (AMS) techniques that have been applied to authentication of muscle foods include, Desorption electrospray ionization (DESI-MS), Easy ambient sonic-spray ionization (EASI -MS), Direct analysis in real-time (DART-MS), Rapid evaporative ionization mass spectrometry (REI-MS), MasSpec pen, Liquid extraction surface analysis (LESA-MS) and Sheath-flow probe electrospray ionization (sfPESI-MS).

2. Smart Packaging

Food packaging plays a vital role in its safety and shelf life of products. Most foods' quality and shelf life are strongly affected by the packaging, storage temperature and distribution conditions. The limitation of conventional plastic packaging in demonstrating accurate and real-time food expiration dates leads to food waste and food borne diseases. The cause of food spoilage may be due to lipid oxidation, protein oxidation, microbial activity, enzyme degradation, or changes in pH. A realistic and real-time method for monitoring the quality and safety of the food supply chain is necessary for standardizing the food market and safeguarding consumer rights and interest.

Intelligent packaging emphasizes the capacity to detect or quantify a property of the packed food item, the atmosphere inside the box, or the transportation environment. Active packaging refers to a package that includes active capabilities beyond passive protection and confinement of the food product. The information gathered by intelligent packaging may be sent to consumers or utilized to activate the features of active packaging. Intelligent packaging and active packaging may collaborate to create “smart” packaging, which combines the benefits of active and intelligent packaging systems.

Smart packaging can overcome these causes of spoilage and wastage. Intelligent packing provides real-time and dynamic information about food quality using indicators and sensors. Active packaging extends food shelf-life and improves quality by controlling the level of oxygen and minimizing bacterial proliferation. Smart packaging is characterized as a packaging system capable of performing intelligent functions, including recording, detection, communication, sensing, and tracking.

2.1 Sensors and Indicators in packaging

There are different smart packaging techniques for assessing the freshness of food products. These smart packages comprise indicator-based (freshness, gases, time-temperature), sensor-based (biosensors and chemical sensors), and paper-based/arrays.

2.1.1 Freshness indicator (FI) is a crucial feature of intelligent packaging and is usually accessible in two kinds: indicator card (label) and indicator film. The colour changes of FI generated by a food's specific volatile components, identify the food's freshness quickly. FI has potential to offer qualitative or semi-quantitative information on food quality changes caused by physiological or microbiological growth without damaging food packaging, allowing consumers to evaluate food quality intuitively and scientifically.

2.1.2 Time and Temperature Indicators (TTIs) are simple but crucial tools that function based on the temperature of both the product and its container. These indicators or processors monitor and display temperature. They are further categorized depending on their functions as time-temperature indicators, essential temperature/time integrators, and critical temperature indicators. Time and temperature indicators (TTIs) are easy-to-use and cost-effective tools for keeping track of a food package's temperature data from the moment it is packed through the packaging, storage, distribution, and retail stages. While numerous Time-Temperature Indicators (TTIs) have been designed and utilized to monitor shelf-life and storage properties in dairy products, other seafood, frozen foods, fish products and chilled meat, with the goal of enhancing intelligent packaging methods, there remains a lack of research dedicated to liquid food intelligent packaging.

The challenges in packaging systems include the respiration rate of fresh fruits and vegetables, the alteration of gas concentrations, gas leaks into or out of packaging materials, and the gas from microbial activity. For

resolving this, gas indicators have been developed. By changing colour in response to a specified chemical or enzymatic reaction, these indicators give information on the oxygen or carbon dioxide gas concentration inside the packing material. These indicators may give information on the presence or absence of a gas by direct interaction with the foods. Typical forms of gas indicators include labels, tablets, printed layers, and laminated polymer films.

2.1.3 pH indicators exhibit colour changes based on chemical reactions or microbial growth. pH alterations are directly affected by the spoilage of food products. The difference in pH can occur in packaged foods when they tend to decompose, which results in an alkaline pH environment, or when fermentation happens because of microbial activity. Foods with high water activity, such as meat and seafood-based products, are more susceptible to microbial biodegradation. The pH within the package varies due to the accumulation of volatile nitrogen compounds (containing ammonia and amines, such as total volatile nitrogen compounds (TVB-N)) caused by the pH variations because of bacterial spoilage which is visible in the colour change of the pH-responsive colour indicators.

2.1.4 Natural components-based pH indicators: The growing demand for consuming natural/organic products and using natural pigments to produce indicators is a healthier and safer replacement for synthetic colorants. It has been shown that natural bio-based extracts may be employed efficiently as dyes in pH-based food quality indicators in intelligent packaging technologies since they operate based on overall colour difference values over a pH range. Previous investigations have highlighted the potential of natural dyes, pigments, and food colourings as intelligent packaging system indicators.

Food packaging should not negatively affect the environment and so, biodegradable and conveniently recyclable materials are becoming more popular. Special standards are imposed on food packaging to ensure that it does not compromise the safety and health of customers and does not leach dangerous compounds from the plastics manufacturing into the packed food. Several substances that may migrate from food packaging include plasticizers, antioxidants, heat and light stabilizers, slide agents, antistatic agents, lubricants and nanoparticles. Some chemical substances (such as A diglycidyl ether, bisphenol A, primary aromatic amines, bisphenol, and phthalate) are detected in food because of packing migration and the migration of harmful/hazardous compounds into food is strictly regulated and cannot exceed permissible levels. Consequently, there is a growing interest in natural chemicals that may be employed as process additives in polymers.

Indicators of food freshness based on natural dyes, such as curcumin, grape peel, and beetroot extracts, have also been investigated for detecting deterioration of food (cod meat). These natural pigments are mostly containing anthocyanins molecules which have a pH-dependent colour, primarily due to the chromophore of the anthocyanin molecule, which undergoes changes in its conjugation and structure in response to pH changes, resulting in different colours (Fig 2).

pH indicator with anthocyanins derived from various natural sources into polymer coatings have been developed and characterized. One using sago starch and anthocyanins from torch ginger by Mei et al (2020) demonstrated that elongation at break, moisture content and water solubility were improved with addition of torch ginger compared to control. A pH sensitivity analysis showed that the colour of films containing TGE extract changed from pink to slightly green as the pH increased from pH 4 to 9. Therefore, the pH-sensitive film with torch ginger extract can be used to detect food freshness or spoilage.

The addition of grape anthocyanin (1.0 g/100 g, as natural pH indicator) to chitosan films had no impact on the mechanical properties of the films, including tensile strength and stiffness. However, it resulted in a reduction of 47 % in elongation and a 48 % decrease in water vapor permeability (WVP) compared to films without the indicator.

An intelligent pH-sensing indicator made of gelatin film and anthocyanin extracted from dragon fruit skin, showed increased moisture content, thickness, and water solubility, but decreased WVP and light transmittance. It was found to be a useful visual indicator of pH variations during food storage.

Typically, natural dyes like anthocyanins, carotenoids, betalains, curcumin and chlorophylls serve as food indicators. These not only detect food quality changes but also offer additional benefits, such as antibacterial and antioxidant activity. To meet pH-responsive food packaging requirements, improvements are needed in the colour rendering range, colour sensitivity, and dye penetration of natural pigments. Natural dyes are often utilized for intelligent packaging, particularly food freshness tracking, because to their abundant supply, ease of access, safety, broad signaling range, excellent pH-responsiveness, and other characteristics. Natural pigments' poor stability, varied solubility, and distinctive pH sensitivity are thought to be their key limiting factors.

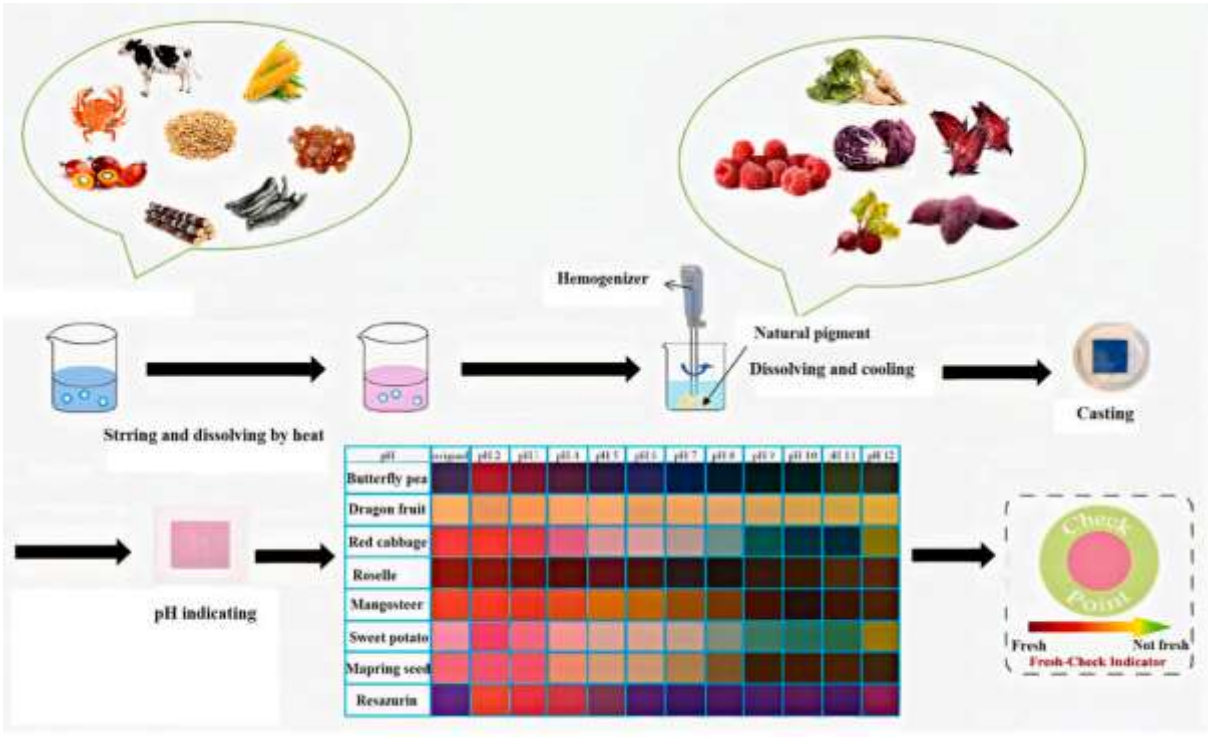

Fig 2 Process Flow of Natural pH responsive colour indicator films (Jafarzadeh et al, 2024)

2.1.5 Nano Materials in pH Sensitive Indicators The performance of pH-sensitive indicators can be enhanced by incorporating various types of nanomaterials/nanostructures. These include antibacterial activity, stability, sensitivity, oxidation resistance, improvement of tensile strength (TS), water resistance, mechanical characteristics, and so forth. Cellulose nanocrystals incorporated in chitosan composite films improve their TS, water barrier, and UV barrier properties. Also, zinc oxide nanoparticles (ZnO) in konjac glucomannan/chitosan-based and gelatin/agar active packaging systems showed antibacterial capabilities. Additionally, silver nanoparticles (AgNPs), which can increase the stability of the films, have been utilized in anthocyanin-based films. Using natural pigments and titanium dioxide nanoparticles (TiO2 NPs) improved

the films' mechanical properties and moisture resistance. Most of nanomaterial-based pH indicators consist of following nano-biopolymers, carbon-based nanostructures, functional metallic nanoparticles, nano-metal oxides incorporated polymers, and biopolymers to improve for food monitoring quality. Chitosan, cellulose, gelatin, starch, and polyvinyl alcohol (PVA) are typical examples of biopolymers/polymers that are often utilized.

Carbon dots (C-dots) can act as sensors in intelligent food packaging since they are fluorescent and possess unique properties. In acidic conditions (low pH), carbon dots exhibit protonation of functional groups, causing changes in their electronic structure. This results in a shift in absorption and emission wavelengths, leading to a colour change. Conversely, at high pH, functional groups deprotonate, leading to an altered electronic structure as well as colour changes. One of the most promising carbon-based nanomaterials is graphene oxide (GO) nanoparticle/nanosheets. GO exhibits outstanding bio-safety performances, especially at low concentrations, in addition to their unique mechanical and thermal properties. Addition of GO to the prepared freshness indicator film not only enhanced the mechanical properties and thermal stability, but also significantly improved the moisture content, water solubility, surface hydrophilicity and biosafety. The colour changes of the freshness indicator were observed from red/pink to yellow with the increase of pH from 2 to 13 when tested in lamb samples stored for 96 h at 4 °C. The formation of volatile nitrogen compounds causes a rise in the pH of the meat sample to 7.8 (light indigo) from a pH of 5.8 (beige).

Sulfur nanoparticles (SNPs) exhibit a variety of biological functions including anti-inflammatory, antibacterial, and antitumor properties. SNPs have been employed in developing antimicrobial films demonstrating considerable antimicrobial activities against bacteria that lead to food borne disease. A smart pH-responsive packaging film indicator was made by utilizing SNPs, curcumin, and pectin to detect the freshness of shrimp samples. SNPs improved the indicator film's UV barrier characteristics, thermal stability, antibacterial activity, antioxidant activity, and sensitivity to ammonia vapor. The pHsensitive indicator film showed a noticeable colour shift from yellow to orange when fresh (6.3) to the spoiling stage (7.1) after 36 h of storage at 25° C. **AgNPs** are among the most extensively employed metal nanoparticles. A pH-sensitive freshness indicator based on κ-carrageenan polymer filled with AgNPs and anthocyanin to monitor marine fish's (seabass, stored at 4° C) freshness in real-time was developed. The colour of the film which was purple (around pH 5–6) at the beginning changed to blackish purple (pH 8), after 4 days and on the last day, it was dark green (pH 10). Similarly, ZnO NPs and TiO2 NPs have been used successfully in biopolymer-based food packaging material for shrimp and prawn.

2.1.6 Papers based sensors are an economically viable option due to the use of a low-costbase material and their combination with smartphone facilities, their communication offers scope for expanding application of intelligent packaging. Their advantages include high specific strength and stiffness, lightweight, nontoxicity, abundance, recyclability, biodegradability and low cost. Paper-based sensors offer consumers and scientists a fast and easy-to-use detection technique for food freshness. Therefore, through integrating effective or required chemicals and polymers into the cellulose network, cost-effective paper-based technologies for filtering, printing, packaging, and sensing have developed quickly in recent years.

A non-destructive and paper-based sensor for trimethylamine (TMA) and TVB-N determination upon spoilage of Grass carp samples was recently developed by Sun et al (Sun et al, 2021). A mixture of carboxymethyl cellulose, glycerin, and natural purple cabbage pigment was used to produce a printable ink, and this ink was printed on the filter paper by the screen-printing method. The resulting printout was then applied to

modified atmosphere packaging (MAP). At 25 °C, the sensor's colour changed from purplish red to blueish violet in 18 h, and at 4 ◦C, it turned to blueish violet in 3 days as seen from Fig 3. The storage of grass carp show that the paper sensors have the necessary visual discriminating capabilities.

Fig 3. Changes in paper sensors' colour indicating grass carp freshness within 24 h at 25 °C (Sun et al, 2021).

2.1.7 Lab-on-paper optical sensors Optical sensors are analytical tools that are chemical or bio-based sensors since they combine optical transducers with chemical recognition phases (sensing receptors). Typically, optical sensors are tools that can identify and measure a range of light characteristics, including frequency, wavelength, polarization, and intensity. This type of sensor is frequently employed to evaluate food quality parameters including pH, temperature, and spoilage.

Weston et al. developed a ZnO solution with the incorporation of conjugated polymers and polydiacetylene (PDA) to assess cream milk freshness. A lab-on-paper colorimetric sensor for bacterial spoilage in packaged meat was developed using two pH-indicator dyes, bromocresol purple (BCP) and bromothymol blue (BTB), to produce the on-package sensor, which was then bonded to the inside of the packing film before storage. Circular filter-paper pieces, measuring 15- and 35-mm diameter, were used as sensory material and applied to the inner side of chicken fillet packages, allowing direct contact with the package atmosphere. The samples stored at 25°C and 4°C, separately, were periodically tested for microbiological population, pH, and TVB-N content. In the presence of humidity, the dye in the sensor can interact with the emerging gaseous by products of bacterial decomposition to produce the required colour shift. A smartphone camera was used to take sensor photos, which were then edited with an Android program that comes pre-installed to read colour changes and offers qualitative and quantitative data regarding the freshness of the meat. For BTB and BCP, the linearity ranges were determined to be 11.2 × 103 to 1.12 × 106 and 38.0 × 103 to 1.12 × 106 CFU/g, respectively. The obtained calibration plots showed high the correlation coefficients (r) for BTB and BCP of 0.9998 (slope: 2.48 g/CFU) and 0.9999 (slope: 1.95 g/CFU), respectively. The as-prepared sensor was used effectively to assess the freshness of chicken meat products for 8 days in the refrigerator and 3 days at room temperature as evident from Fig 4.

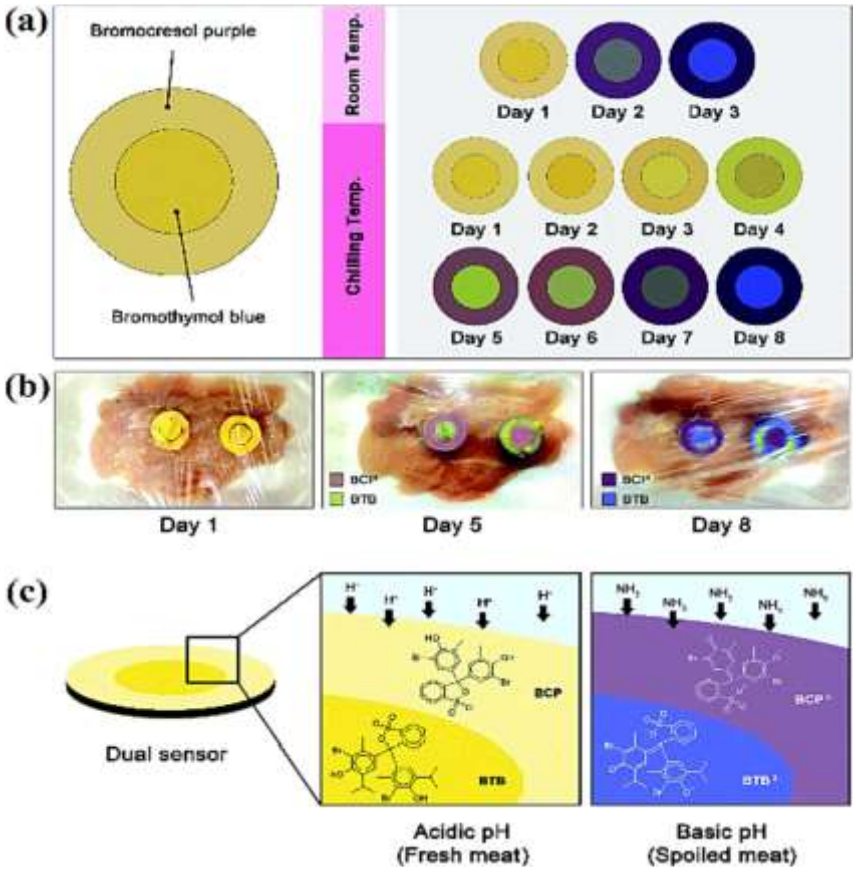

Fig 4 (a) The lab-on-paper colorimetric sensor structure and the colour changes in chicken meat, at room and chilled temperature.

(b) Smart phone images of test samples at 4°C on days 1, 5, and 8.

(c) Colour responses of BCP and BTB indicators in fresh and spoiled meat samples (Dena et al, 2021).

2.1.8 Smart Phone Diagnostics

The growing need for technology and the most recent technical developments, have made cell phones an inevitable part of daily life. Being highly functional and easily transportable, they provide enhanced communication capabilities due to their integrated sensors. By connecting the biosensors to cell phones, food assessment may become simple and broadly accessible. Toxins, allergens, pollutants, and viruses may all be detected and/or determined with these convenient and portable detectors. Food products can get contaminated at any point in the food chain - production, sale, storage, transportation and consumption. The traditional detection techniques have been duplicated by smartphone-based biosensors, but they are more effective. Table 1 summarizes recently developed smartphone-based sensors for food spoilage applications. Further, smartphones are great data processors due to the recent operating systems, sensors, transducers, and data processors.

Table 1 Smartphone-assisted detection of food spoilage studies (Jafarzadeh et al, 2024)

Food sample	Target	Reagent	Detection tool	LOD/LOQ/DR
Fish	Biogenic amine (Cadaverine)	Synthesized PTCN	Fluorescence	46 nM
Fish	Histamine	CDs	Visual monitoring	36 nM
Beef, fish, chicken, and pork	TVB-N	Poly(vinyl alcohol)/sodium alginate (PVA/SA) hydrogel	pH, RGB analysis	–
Fish	Biogenic amines	NH_2-rich lanthanide MOF coupled fluorescein 5-isothiocyanate	Fluorescence	2.17 mg/L
Beef meat and salmon fish	Biogenic amines	Hydrolysis-induced silver metallization of Au nanorods	Colorimetric	8.6×10^{-9} mol.dm^{-3}
Beef meat	Microbial contamination	–	Mie scatter angle analysis	10 CFU/mL
Beef, fish, chicken, and pork	Biogenic amines (NH_3, putrescine, cadaverine)	p-Toluene sulfonate hexahydrate doped nanostructured polyaniline (PTS-PANI)	NFC tag, Smartphone readout	5 ppm
No specific food sample	Microbial contamination (*S. enteritidis* and *E. coli*)	Mesoporous Pd@Pt nanoparticles	Colorimetric	20 CFU/mL for *S. enteritidis* and 34 CFU/mL for *E. coli*
Milk, cheese, and water	Microbial contamination (*S. enterinidis*)	The combination of the magnetic-antibody and the HRP - Antibody - nanoflower based ELISA	Colorimetric	1.0 CFU/mL
Yoghurt and egg	Microbial contamination (*E. coli*)	Compact laser-diode-based photosource, a long-pass thin-film interference filter and a high-quality insert lenses on the Smartphone	Fluorescence	1.0 CFU/mL and 10.0 CFU/g
No specific food sample	LPS	A grating coupled SPR Smartphone spectrometer	SPR	32.5 ng/mL
Fruit juice	Malathion	A 3D printed chip	Colorimetric	51.9 ng/mL
Fruits and vegetables (Apple, tomato, grape, green pepper)	OPPs	OPH-based biosensor system on the index finger of a flexible lab glove	Enzyme-immobilized biosensing	–

NFC: Near-field communication; SPR: Surface Plasmon Resonance; LPS: Lipopolysaccharides.

OPH: Organophosphorus hydrolase; MOF: Metal-organic framework, PTCN: A ratiometric fluorescence probe.

Anthocyanins-doped fish gelatin (FG) films were developed for food freshness monitoring. CDs were used as potential crosslinkers in producing FG films. Sensor films with different CD concentrations were prepared, and their colour changes upon interaction with ammonia vapor were utilized to develop the mobile application monitoring food spoilage. A custom-designed smartphone app (Smart Food) with picture processing capabilities was created for the quantitative study of food deterioration. The Smart Food's embedded analysis tool tracks and displays the level of spoilage and notifies the user of the food's current freshness state.

2.1.9 Intelligent Probes are given in the form of some pattern which increases its attractiveness and usability for a customer such as QR-code like sensor, happy/sad face pattern or imprinted information being visible when the sensor recognizes a product as spoiled. These are more complex but much more attractive solutions from the commercial perspective and consumer friendly (Fig. 6). The colorimetric anthocyanins-based sensors for freshness monitoring of chicken, shrimp and pork meat have been successfully applied by immobilization of various sources derived anthocyanins in different matrices and carriers. For example, Franco et al, (2021) reported a happy/sad face indicator of chicken freshness based on anthocyanins obtained from black carrot immobilized in cellulose acetate film. The adhesive paper with printed circular Emoji - happy and sad faces playing a role of pH inactive reference layer whereas the eyes and mouths were filled with pH sensitive anthocyanin/cellulose acetate composite.

Fig 5. Different forms of food freshness/spoilage indicators with increased customer attractivity: (A) QR-code like; (B) Progress bar; (C) Imprinted information; (D) Happy/sad face (Jafarzadeh et al, 2024)

Most current solutions are based on continuous monitoring of pH changes in the product environment. Observable pH variations can be related to different chemical changes of the product during the storage time – among others: generation of ammonia, hydrogen sulfur, CO2 or biogenic amines. In many cases, the colorimetric response of the sensors allows to differentiate the spoilage related chemicals and thus their quantitative or semi-quantitative analysis is possible. It is to be noted that bio-based and biodegradable

polymers based on PVA, cellulose acetate or agar were applied as a sensor matrix which is very important in today's context of sustainability.

3. Natural Preservatives

The use of natural preservatives is one of the most recent trends among consumers and the scientific community. Among the different properties of these natural preservatives, antioxidant and antimicrobial activities are highlighted for their combined use to prevent contamination and the loss of the sensory quality characteristics of foods. The compounds most used can be classified according to their origin: vegetal (e.g., essential oils and plant extracts), animal (such as chitosan, lysozyme) or microbial (bacteriocins) sources. However, the same compounds can be included in **edible films and coating for packaging purposes**. Oregano, thyme, or rosemary has been successfully used to preserve not only muscle foods but also other such plants (e.g., orange, pomegranate). Essential oils (EOs) and phenolic compounds, together with terpenes and alkaloids are secondary metabolites present in plants which usually present antioxidant and antimicrobial activities, among others. The different advantages over synthetic materials are their high efficacy in retarding food degradation, extended shelf life, lack of toxicity, as well as an eco-friendly character.

The main difference between films and coatings is related to their application procedure. Edible films are prepared separately as solid sheets and then used to cover the surface of the food, whereas coatings are formed directly onto the food surfaces. Most of the edible materials are formed from natural biopolymers from animal-derived compounds (chitin, chitosan), plant-derived (cellulose, starch, pectin,), seaweed-derived (agar, alginate, carrageenan) as well as microbial-derived (pullulan, xanthan gum). In addition, lipid compounds such as oil, resins or waxes have been used and protein-based films (gelatine, collagen and milk, soy or whey proteins) are also being widely investigated.

4. Block Chain Technology

The food industry has seen unprecedented digital shifts due to the COVID-19 pandemic, putting enormous pressure on food supply chains, with consumers being at the centre of this transformation. Blockchain technology, which is a decentralized, distributed data structure and public digital ledger, has been suggested for food traceability and enhancement of sustainable operations. This technology provides information on the entire history of a product as it travels along the whole supply chain. For instance, it can be applied to trace fish lots, back and forth, throughout the entire fisheries value chain.

Conclusion

The need for ongoing innovation and cross-disciplinary cooperation to advance this area is apparent.

The final quality of the bought food in some day depends on its delivery chain history. In the case of perfect production and storage conditions over the course of the whole product lifecycle its final shelf life can be much longer than suggested by “best before” date. On the other hand, if the condition on some production or delivery stage differed from optimal, the product spoilage may be accelerated.

At present, intelligent/smart food packaging besides active food packaging which represents the separate technology in the food industry can respond to the expectations. The practical potential of intelligent probes for assessing food freshness utilizing naturally sourced pigments for real-time quality monitoring of perishable foods is immense. Incorporating colorimetric and paper-based indicators based on natural dyes into food packaging has multiple advantages, including the timely disclosure of real-time quality details, the facilitation of decision making, the long-term reduction of food waste, the decrease of foodborne diseases,

spoilage, and deterioration of food products, and the enhancement of the packaged product's appeal to retailers and consumers. Intelligent packaging offers significant implications for public health and environmental sustainability by addressing these issues. Therefore, as scientific research and related technologies develop, colorimetric and paper-based probes that monitor food quality and safety will become one of the future research trends. The barriers of the laboratory scale successes need to be overcome, because of the high cost and lack of adaptability to an industrial environment. Another factor that hinders the wider acceptance is the technical and technological skill gap, one of the key barriers to the adoption of new technologies. Multidisciplinary approaches and connectivity between various domains, particularly, physical, biological, and digital fields are essential to meet the challenges and take forward these innovations.

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Nutrigenomics

21. Nutrigenomics for Precision Nutrition

Nutrigenomics, the study of how nutrition and genes interact offer a personalized approach to diet and health. To identify genetic variations influencing metabolic illness such as type 2 diabetes, obesity and insulin resistance, it employs transcriptomics, metabolomics and genomics. Important discoveries include the utilization of branched chain amino-acid as a biomarker, tissues- specific insulin resistance, and the impact of gut flora on dietary responses. As research progresses, nutrigenomic holds promise for precision nutrition, enabling personalized dietary treatments to improve health outcomes and prevent chronic diseases.

1. Introduction

Nutrigenomics is a vibrant and rapidly expanding field that examines the complex relationship between genes and nutrition. It provides a basis for understanding how our genetic makeup influences our ability to absorb and respond to food. Nutrigenomics, which highlights the distinct genetic components that influence dietary demands and responses, has brought to a more individualised approach to nutrition. Nutrition research has traditionally focused on general dietary recommendations for societies. This individualized approach is becoming increasingly relevant in the context of chronic disorders like obesity, diabetes, and cardiovascular diseases, which are influenced by lifestyle variables like nutrition as well as genetic predispositions. Nutrigenomics seeks to identify these genetic variations to develop personalized nutrition therapies that optimize health outcomes.

2. Nutrigenomics - Precision Nutrition's Future

By using molecular techniques like transcriptomics, metabolomics, and genomics, researchers may examine how specific genetic variations impact an individual's reactions to different diets and nutrients. These advancements offer potential for precision nutrition, allowing dietary strategies to be customized based on an individual’s genetic makeup, metabolic state, and lifestyle habits. A major goal of nutrigenomics is to understand the genetic components that lead to insulin resistance, a feature of many cardiometabolic diseases.

Understanding the genetic factors that contribute to insulin resistance, a characteristic of many cardiometabolic disorders, is one of the primary objectives of nutrigenomics. Fat storage is encouraged, and blood sugar levels rise when muscle, fat, and liver cells become less sensitive to insulin. This condition is known as insulin resistance. It's interesting to note that different people and even different human tissues have different levels of insulin resistance. As a result, the idea of tissue-specific insulin resistance has been developed, implying that different organs have unique resistance patterns influenced by both environmental and hereditary factors.

Using metabolomics, lipidomics, and transcriptomics, recent studies have shed light on the distinct molecular markers associated with insulin resistance in numerous organs. Women's hepatic insulin resistance, for example, it has been associated to specific lipid profiles, including higher levels of triacylglycerol (TAG) and diacylglycerol and lower levels of odd-chain and extremely long-chain TAGs. The absence of these changes in lipid metabolism in males raises the possibility that gender differences play a role in the development of insulin resistance. Using RNA sequencing to study gene expression in adipose tissue, other studies have found

that individuals with hepatic insulin resistance have upregulated genes associated with extracellular matrix remodelling, while those with muscle insulin resistance have more active genes related to inflammation than others.

3. Understanding the Genetic Code for Ideal Diet

Finding the right diet for each person based on their genetic composition is one of the most fascinating features of nutrigenomics. Branching-chain amino acids (BCAAs) have been linked in a growing number of studies to type 2 diabetes and insulin resistance. In particular, the BCAA group amino acids tyrosine and phenylalanine have been associated with decreased insulin sensitivity. Interestingly, more study has suggested that BCAAs may also help to improve insulin sensitivity in certain situations, such as while trying to lose weight.

Although there is a strong link between BCAAs and insulin resistance, the exact mechanisms by which these amino acids contribute to metabolic diseases. However, the ability to use nutrigenomic techniques to identify biomarkers such as BCAAs has provided crucial new insights into the genetic and metabolic aspects of cardiometabolic illnesses. As additional studies are conducted, nutrigenomics should uncover more molecular pathways and genetic markers that can be targeted for the prevention and treatment of different diseases.

Another important area where nutrigenomics is progressing is understanding the role of gut flora in nutrition and health. The gut microbiome, which is made up of trillions of bacteria, is crucial for food metabolism, immune response, and overall health. It is increasingly recognized that the composition and activity of the gut microbiota might influence the body's response to specific nutrients and meals. By combining genomic and metabolomic data, scientists are learning how individual genetic profiles may interact with the gut microbiota to change meal responses.

4. The Intersection of Nutrition Science and Genetics

The relationship between nutrition science and genetics is one of the most fascinating research topics in the field of human health. Scientists are exposing the complex connections between genetic expression and nutrition by combining information from high-throughput technologies such as genomics, metabolomics, and microbiomics. One of the key benefits of this approach is identifying the metabolic pathways that underlie diseases including obesity, insulin resistance, and cardiovascular disease.

Nutrigenomics, which examines the effects of certain genetic variants on gene expression and nutrition metabolism, has the potential to identify novel biomarkers and therapeutic targets for the prevention and treatment of disease. For example,

· Apolipoprotein M (apoM), a newly identified adipokine associated with healthy adipose tissue, has been demonstrated to express itself more when calories are restricted.

· Randomized controlled trials (RCTs) has shed light on the function of the gut microbiota in nutrition. Dietary modifications, such as consuming prebiotic supplements like galacto-oligosaccharides, have been shown to alter the composition of the gut microbiome and impact metabolic outcomes.

5. Conclusion

Nutrigenomics is revolutionizing nutrition research by providing a more personalized strategy for preventing food-related illnesses. By combining the capabilities of genomes, metabolomics, and microbiome research,

nutrigenomics is gaining significant understanding of the genetic and molecular processes primary metabolic diseases such as obesity, insulin resistance, and type 2 diabetes. As research develops, nutrigenomics could play a significant role in precision nutrition programs that tailor health outcomes to each person's unique metabolic state and genetic profile.

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