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Agro-based Substrates Potentials for The Production of Metabolites: A Mini Review

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Abstract—*Natural products are compounds produced by living organisms and are categorized as Primary Metabolites (PMs) and Secondary Metabolites (SMs). Plant PMs are crucial for plant growth and reproduction because they directly affect living cell processes, whereas plant SMs are organic chemicals that are directly engaged in plant defense and resistance. Terpenoids, phenolics, and compounds containing nitrogen are the three main types of SMs. The SMs have a variety of biological qualities that can be used as food additives, flavourings, plant disease control, and to help plant cells better respond to the physiological stress response, in addition to enhancing plant defenses against herbivores. The present study investigated the characterization, origins, types, applications, and/or roles of primary and secondary metabolites as by-products of microbial metabolisms from a variety of sources such as plants, microorganisms, including bacteria, actinobacteria, and fungi, as well as their production and classification in various fields. These metabolites are essential for developing new chemical and pharmaceutical treatments for conditions that affect both plants and animals. Alcohols, antioxidants, phytochemicals, bioactive compounds, food-grade acids (acetic, lactic, citric, fumaric, etc.), and several value-added products with industrial and human uses are among the many products that are derivable from metabolites. The beneficial uses of microbial metabolites in the food, chemical, and pharmaceutical industries as well as other related industries that address human nutritional and health needs are reviewed in this work to serve as basal understanding of metabolites, their sources, applications and implications for sustainable development.*

Keywords—Agro-Based Substrates, Fermentation, Metabolites

1. INTRODUCTION

A metabolite is any intermediate or product resulting from metabolism, in which nutrients are broken down to generate energy and to give simpler molecules (catabolism) metabolites themselves may be used to form more complex molecules (anabolism). Plants-based metabolites, widely used in agricultural, medical and pharmaceutical products, are divided into two main categories namely Primary Metabolites (PMs) and Secondary Metabolites (SMs). The Primary metabolites include carbohydrates, proteins, fats and alcohol, which are involved in growth, development and reproduction (Elshafie *et al*., 2023). Plant secondary metabolites are unique sources for pharmaceuticals, food additives, flavours, and other industrial materials and the use of plant cell cultures has overcome several inconveniences for the production of these secondary metabolites. Organized cultures, and especially root cultures, can make a significant contribution to the production of secondary metabolites. Secondary metabolites are described as organic compounds which were not directly involved in the normal growth, development, or reproduction of an organism (Guerriero *et al.*, 2018).

Agro-based substrates are vital for metabolite synthesis due to their abundance, affordability, and high nutritional content. These substrates are effective and durable feedstock for microbial fermentation operations; they are derived from agricultural waste and by-products such as fruit peels, husks, and crop residues. They provide essential carbon, nitrogen, and other micronutrients to promote the growth of microorganisms and the production of significant primary and secondary metabolites, including organic acids, enzymes, antibiotics, and bioactive compounds. The use of agro-based substrates promotes environmental sustainability and reduces manufacturing costs by promoting waste valorization and circular bio-economy practices (Cuadrado-Osorio *et al*., 2022).

2.0 TYPES OF METABOLITES

Plants-based metabolites, widely used in agricultural, medical and pharmaceutical products, are divided into two main categories namely primary metabolites (PMs) and secondary metabolites (SMs). The Primary metabolites include carbohydrates, proteins, fats and alcohol, which are involved in growth, development and reproduction (Elshafie *et al*., 2023).

2.1 Primary Metabolites

A metabolite that is directly engaged in normal growth, development, and reproduction is known as a primary metabolite. It often carries out an innate physiological role within the body. Most organisms or cells normally include a main metabolite. It goes by the term "central metabolite," which has a much narrower definition (found in any independently proliferating cell or organism). A few typical examples of primary metabolites are certain amino acids, acetic acid, citric acid, ethanol, and lactic acid (Irchhaiya *et al*., 2021). Primary metabolites are biochemical substances that are always beneficial (Ofoedum *et al*., 2024).

2.2 Secondary Metabolites

Secondary metabolites are substances that are produced by plants as defense chemicals. Their absence does not cause bad effects on the plants. They include alkaloids, phenolics, steroids, essential oils, lignin, resins and tannins, etc. (Paschapur *et al*., 2021). Many secondary metabolites are used as aromas, resins, gums, flavour enhancers, insecticides and herbicides. On the other hand, the majority of secondary metabolites have found utility in the pharmaceutical industry, given the large number of pharmacological activities that are known about them (Francesca *et al*., 2019). The vast and diverse class of organic compounds known as secondary metabolites is produced in small amounts by plants and serves no direct purpose in vital functions like photosynthesis, respiration, solute transport, protein synthesis, nutrient absorption, and the differentiation or formation of carbohydrates, proteins, and lipids (Francesca *et al*., 2019).

3.0 APPLICATION OF METABOLITES

Naturally occurring plants and their semisynthetic derivatives are the best sources of chemicals with biological activity. Growth and development, respiration and photosynthesis, as well as the synthesis of hormones and proteins, all depend on primary metabolites (PMs), which include carbohydrates, amino acids, fatty acids, and organic acids. Terpenoids, phenolic, and nitrogen-containing chemicals (alkaloids) are examples of plant secondary metabolites (SMs) that influence vegetable colour, shield plants from microbes and herbivores, and function as signal molecules when under stress. Plant secondary metabolites (SMs) are used in a variety of industries, including agriculture, medicine, cosmetics, nutrition, and pharmaceuticals. Here is a thorough breakdown of the different uses for plant secondary metabolites (SMs) that have been described (Elshafie *et al*., 2023).

3.1 Nutritional Uses and Food Industry

The benefits of consuming a variety of fruits and vegetables have recently attracted a lot of attention. These foods include a wealth of bioactive secondary metabolites (SMs), including vitamins, minerals, phytochemicals, essential amino acids, and fibers. However, the stability of those substances can be adversely affected by a variety of physical and environmental factors, such as temperature, lightness, and relative humidity. On the other hand, the beneficial properties of essential fatty acids, which can be obtained from a range of fruits and seed oils, reduce the likelihood of disease. Essential amino acids (EAA) include histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. These amino acids are necessary for eating and other biological processes, including protein synthesis, tissue repair, and nutrition absorption (Aswani and Birudu, 2020).

3.2 Cosmetic Uses

Plant SMs are used in cosmetic preparations because of their low toxicity to mammals. They are used to treat skin conditions such as dryness, eczema, acne, and other skin protective effects by scavenging free radicals. They are utilized as hair colorants and growth promoters. Essential oils (EOs), which can be added to some cosmetic products to give them a nice scent, gloss, and other conditioning qualities, are among the most significant plant SMs. Menthol, for instance, is frequently added to toothpaste and mouthwashes as a flavoring agent. This gives the product a fantastic taste and inhibits the accumulation of plaque, which can cause gingivitis and bad breath. Additionally, menthol combines antibacterial efficacy and mouth protection (Kallscheuer *et al*., 2019).

3.3 Medical/pharmaceutical Uses

A wide range of ailments and illnesses have been treated with plant secondary metabolites (SMs) and their derivatives since ancient times. Numerous plant-based natural chemicals have been used as the primary raw ingredients for several medications. Additionally, plant secondary metabolites (SMs) have been employed as pharmacological probes, prototypes, and drug precursors. Specifically, a sizable portion of medications sold globally are derived from plants, and the pharmaceutical sector today uses several bioactive substances (Elshafie *et al*., 2023).

3.4 Agricultural Uses

Plant protection and growth promotion are two applications for natural products (NPs). Several secondary metabolites found in plants, both microbial and botanical, can stimulate plant hormones and systematic resistance in plants, both of which promote healthy plant growth. Numerous plants, including neem, citrus, sage, menth, garlic, oregano, *moringa*, etc., or their bioactive components, have reportedly been utilized in the literature to treat a variety of bacterial and fungal illnesses, pest infestations, and noxious weeds (Gallardo and Seca, 2022).

4.0 METABOLITES PRODUCTION

With the rapid development of biotechnology, it has overlapped with many fields, from energy to medicine, manufacturing to materials. By utilizing microorganisms with useful traits, which are called cell factories, compounds with outstanding properties can be produced. These compounds produced from cell factories have the potential to replace those produced in traditional chemical synthesis way with less cost and more environmental. Because of the increasing population and exhausted natural resources, sustainability has been emphasized in the production of supplements, including renewable products, utilization of waste and so on. Metabolic engineering is optimizing genetics with biotechnology like gene editing to increase cells' property of producing certain substances. Microbes like cyanobacteria, yeast and other bacteria have been modified with traits to broaden their list of metabolites production and improve their yield.

4.1 Production of Secondary Metabolites from Plants

Secondary metabolites can be produced from plants by conventional methods, immobilization, and in vitro tissues, organs, and cell cultures methods (Ofoedum *et al*., 2024).

4.1.1 Conventional method

The conventional approach for producing secondary metabolites consists of extracting the compounds rather than producing them from plant tissues through various phytochemical procedures, which include supercritical extraction, solvent extraction, and steam extraction. Plant secondary metabolite synthesis and production in vitro has been made easier by recent advances in biotechnological techniques such as tissue culture of plants, enzyme technology, and fermentation technology (Ofoedum *et al*., 2024)

4.1.2 Immobilization

Through covalent bonding, adsorption, or trapping a matrix restricts cells or biocatalysts. The necessary secondary metabolites are produced when the correct physicochemical conditions are fulfilled and an appropriate substrate is introduced. One of the numerous advantages of using a suitable bioreactor system for immobilization is that the process can operate continuously. To produce an immobilized plant cell culture method, however, the discharge of the accumulated product into the surrounding medium needs to happen either naturally or artificially (Thirumurugan *et al*., 2020).

4.1.3 In vitro tissues, organs, and cell cultures

Plant cell and tissue cultures can be routinely generated under sterile conditions from specimens, such as plant leaves, stems, roots, meristems, etc., for both multiplication and the extraction of secondary metabolites. To synthesize the needed metabolite, the following strategies are employed: hairy root culture, callus, shoot, root, and cell suspension. Metabolite production can be accomplished through suspension cultures or disordered calluses, which spread metabolites throughout various tissues. However, the most effective approach is differentiated microplant or organ culture when the desired metabolite is confined to specific regions or parts of the host plant. Since saponins are generated from ginseng roots, in vitro root culture is the preferred technique for saponin synthesis. Similarly, the antidepressants hypericin

and hyperforin found in the foliar glands of Hypericum perforatum are not generated from undifferentiated cells (Thirumurugan *et al*., 2020).

4.2 Production of Secondary Metabolites from Microorganisms

Secondary metabolites are produced by primary metabolic processes. The basic and secondary metabolic pathways that are crucial to the business world are listed in Table 1.

Table 1: Intermediate from primary metabolism and their secondary metabolites derivatives

Intermediates From Primary Metabolic Pathway	Secondary Metabolites Derived

Shikimic acid	Ergot alkaloids, antibiotics: candicin and chloramphenicol
Amino acids	Antibiotics: penicillin, cephalosporins and cephamycins, gramicidin, immunosuppressive cyclosporine
Acetyl-CoA and other Krebs cycle intermediates	Antibiotics: erythromycin, ant parasitic avermectin antitumor doxorubicin, taxol.
Sugar	Antibiotics: streptomycin and kanamycin.

Source: Hussain *et al* (2020)

4.2.1 Liquid fermentation

Secondary metabolites are produced by fermentation in fed-batch, batch, or submerged cultures. Before forming the inoculum, the generating organism meticulously refines its strain. Shake flask cultures are utilized initially, and once they start the active growth phase, they are transferred to a small fermenter and then, finally, to a larger fermenter that includes the production medium. Temperature, pH, agitation and aeration rate, and medium composition are some of the variables that are regulated. An inducer, such as methionine, is added for cephalosporin fermentations, phosphate is regulated for chlortetracycline fermentations, and glucose is avoided for penicillin or erythromycin fermentations (Ozyigit *et al*., 2023).

4.2.2 The method of fermentation in a solid state

The process of solid-state fermentation presents a significant opportunity for the synthesis of secondary metabolites. It is characterized by a microbial culture that grows both within and outside of a solid matrix without the presence of free water (Ofoedum *et al*., 2024). In non-sterile conditions, secondary metabolites can frequently be created in significantly larger yields in shorter amounts of time. It is crucial to mention at this point our own experience in gathering actinobacteria secondary metabolites.

The antibacterial qualities of actinobacteria from both marine and terrestrial habitats have been studied. Thin layer and column chromatography were used to extract and purify the bioactive metabolites, and mass spectrometry, NMR, UV spectroscopy, FT-IR, and mass spectrum analysis were used to determine their structure. Sterosporine, octa-valinomycin, methyl-4,8 dimethylundecanate, and N-isopentyltridecanamide are among the produced metabolites with well-established biological activities (Ofoedum et al., 2024).

5.0 AGRO-BASED SUBSTRATE

Agro-industrial waste is rich in nutrients and promotes the growth of microorganisms. Carbohydrates make up a significant portion of the lignocellulosic wastes seen in most farm environments. Thus, agricultural leftovers can be utilized to produce a range of products with additional value, including metabolites that are significant to the industry. Agro-industrial wastes, including rice bran, maize cob, cashew apples, and sugar cane bagasse, have been extensively studied using various fermentation techniques to produce metabolites (Elshafie *et al*., 2023). Solid-state fermentation holds much potential compared with submerged fermentation methods for the utilization of agro-based wastes for metabolite production. This is because the physical-chemical nature of many lignocellulosic substrates naturally lends itself to solid phase culture, and thereby represents a means to reap the acknowledged potential of this fermentation method (Elshafie *et al*., 2023).

6.0 METABOLITES OBTAINED FROM AGRO-BASED SUBSTRATES

The agro-based substrate contains several metabolites, including organic acids, phenolic compounds, sugars, amino acids, and enzymes, which are produced during fermentation (Gómez-Estaca *et al*., 2020).

6.1 Organic Acids

Organic acids like citric acid, malic acid, and acetic acid have significant industrial applications. Citric acid is widely used as an acidulant, preservative, and in pharmaceutical formulations. Malic acid aids in fatigue reduction and muscle function, while acetic acid has antimicrobial properties and can help lower blood sugar levels (Müller *et al*., 2017; Cai *et al*., 2021; Amin *et al*., 2021). These acids play crucial roles in enhancing the shelf life and safety of food products.

6.2 Phenolic Compounds

Phenolic compounds, such as flavonoids and tannins, are abundant in cashew apple juice and offer powerful antioxidant, anti-inflammatory, and antimicrobial properties. These compounds have medicinal uses, including cancer prevention, heart disease management, and managing oxidative stress (Gómez-Estaca *et al*., 2020). They are used in the food industry for preserving products and in nutraceuticals aimed at improving health outcomes. Flavonoids and tannins' antimicrobial and antiviral properties show promise in drug development (Riaz *et al*., 2018).

6.3 Sugars

The sugars found in cashew apple juice, including glucose, fructose, and sucrose, are fermented into metabolites such as ethanol, which is valuable in biofuel production, food processing, and pharmaceutical industries. Ethanol serves as a renewable energy source, offering an alternative to traditional fossil fuels. These sugars are essential in creating probiotics, syrups, and supplements, and they contribute to sustainable practices in fermentation and biofuel production (Omar *et al*., 2020; Müller *et al*., 2017).

6.4 Amino Acids

Amino acids like glutamine, aspartic acid, and arginine are produced during fermentation and are crucial for human health. Glutamine supports immune function, while aspartic acid aids in energy production. Arginine helps with blood circulation and is important in nitric oxide production. These amino acids are commonly used in functional foods and health supplements aimed at enhancing immune health, athletic performance, and circulation (Bertazzoni *et al*., 2021; Reid *et al*., 2016).

6.5 Enzymes

Enzymes like amylases, proteases, and lipases are produced during fermentation and have valuable industrial applications. Amylases are used in food processing, while proteases and lipases serve in protein hydrolysis and biofuel production. These enzymes can replace chemical synthesis methods, offering more sustainable and eco-friendly alternatives in industries such as food, pharmaceuticals, and biofuels (Tariq *et al*., 2020).

7.0 FACTORS AFFECTING METABOLITES PRODUCTION

Several factors influence the production of metabolites by microorganisms, including:

7.1 Substrate Composition and Properties

The substrate composition is another critical factor influencing metabolite production. Microorganisms require specific carbon and nitrogen sources to grow and produce desired compounds. Recent studies show that agricultural waste, like sugarcane bagasse, can be a sustainable and cost-effective substrate (Sharma *et al*., 2022). The balance of nutrients is also important—too much carbon can inhibit certain metabolic pathways, while nitrogen limitation may trigger antibiotic production (Wang *et al*., 2021). The physical form of the substrate, such as particle size and solubility, further affects how efficiently microbes can break it down and convert it into useful metabolites (Kumar *et al*., 2023).

7.2 Environmental Conditions

Environmental conditions like temperature, pH, oxygen levels, and agitation significantly impact microbial metabolism. Each microbe has an optimal pH and temperature range—for instance, bacteria often prefer neutral pH, while fungi thrive in slightly acidic conditions. Oxygen availability is particularly crucial; aerobic conditions support oxidative metabolism, while anaerobic conditions promote fermentation (Martinez *et al*., 2021). In industrial settings, bioreactors are carefully controlled to maintain ideal conditions, with sensors adjusting pH, temperature, and oxygen in real-time (Lee *et al*., 2023).

7.3 Bioprocessing Techniques

Bioprocessing techniques play a key role in maximizing metabolite yields. Batch, fed-batch, and continuous fermentation methods each have advantages depending on the microbe and desired product (Gao *et al*., 2021). Emerging technologies like adaptive laboratory evolution (ALE) help create robust microbial strains that perform well under industrial conditions (Javed *et al*., 2023). By optimizing these factors—strain selection, substrate, environment, and processing—researchers and industries can enhance the efficiency and sustainability of microbial metabolite production for applications in medicine, agriculture, and biofuels.

7.4 Microorganism Strain and Species

Microbial metabolite production is primarily determined by the strain and species of microorganism used. Different microbes have unique genetic blueprints that dictate their metabolic capabilities. For example, *Aspergillus niger* excels in citric acid production, while *Streptomyces* species are known for antibiotic synthesis. Advances in genetic engineering, like CRISPR-Cas9, now allow scientists to modify microbial DNA to boost metabolite yields (Zhang *et al*., 2021). Additionally, the growth phase of the microbe plays a role—primary metabolites (e.g., amino acids) are made during active growth, while secondary metabolites (e.g., antibiotics) often form during stress or stationary phases (Liu *et al*., 2023).

Microorganisms are the oldest living entities on Earth, dating back around 3 billion years. They are microscopic living organisms that are essential to fermentation. They are in charge of transforming unprocessed components into the diverse range of flavours, scents, and textures that characterize fermented goods (Fuerst, 2014). Microorganisms differ among species in terms of size, shape, appearance, and mode of survival. The majority of fungi and numerous protozoa species are the largest microbes (Hayet *et al*., 2021).

8.0 TYPES OF MICRO-ORGANISM

Microbes, often known as microorganisms, are microscopic living organisms that are essential to fermentation. They are in charge of transforming unprocessed components into the diverse range of flavours, scents, and textures that characterize fermented goods (Fuerst, 2014). Microorganisms exist in millions of different species, much like there are millions of different species of plants and animals on the planet. In conditions unfit for human habitation, microorganisms can thrive. Microorganisms can be found everywhere in the environment, including your kitchen and the interiors of creatures like humans and Antarctica (Azeez, 2019). Three of the most prevalent types of microorganisms used in fermentation are moulds, yeasts, and bacteria (Fuerst, 2014). Because they are so much smaller between hundreds and thousands of times smaller microorganisms can only be viewed under a microscope.

8.1 Bacteria

Numerous varieties of bacteria can be found in food, and while the majority of them cause food to spoil, others, like Clostridium, are in charge of producing toxins like botulin, which gives humans botulism. As a result, the role that bacteria play in the fermentation processes of food is often overlooked. Lactic acid bacteria, including *Lactobacillus, Pediococcus, Streptococcus, Oenococcus*, and others, are the most common microorganisms found in fermented foods. These bacteria are followed by species of *Acetobacter,* which convert alcohol to acetic acid. Acetic acid has long been fermented to create cider vinegar and other fruit vinegar. A third significant group of bacteria in fermentation is the *Bacillus* species (*Bacillus subtilis, B. licheniformis*, and *B. pumilus*), which causes alkaline fermentation (Harrison and Solomon, 2024).

8.2 Yeasts

*Schizosaccharomyces p*ombe and *S. boulderi* are the primary yeasts used in traditional fermented drinks, especially those made from maize and millet. The yeast *Saccharomyces cerevisiae var. carlbergenisis* is used to brew beer. *Schizosaccharomyces pombe* is capable of decomposing malic acid into ethanol and carbon dioxide, which is why it has been used successfully to lessen the acidity of plum and grape musts. *Rhodotorula* and *Cryptococcus* are two of the many yeasts that can produce the pigment that is useful as a bicolour (Patel and Patel, 2022).

8.3 Moulds

Moulds are essential food spoilers and preservers in the food processing industry. Many moulds can produce significant industrial enzymes, such as pectinase from *Aspergillus niger*. Cashew apple juice and other waste products are converted to citric acid using *Aspergillus species* (Patel and Patel, 2022). Food degradation is often the result of negative food changes brought on by the *Aspergillus species*. On the other hand, cheese ripening and flavour development are associated with *Penicillium* species. Although fruit flavour is produced by *Ceratocystis species, penicillium* is the cause of the synthesis of toxins such as *patulin* (Chen, 2023).

Fermentations based on mould are responsible for producing distinctive goods like tempeh and blue cheese. These filamentous microbes break down complex substances, changing the finished product's flavour, texture, and scent. Penicillium roqueforti, for example, gives blue cheeses their characteristic blue veining (Steinkraus, 2019).

Through fermentation, microorganisms growing on inexpensive carbon sources can produce valuable products such as amino acids, nucleotides, organic acids, and vitamins which can be added to food to enhance its flavour or increase its nutritive values. The contribution of microorganisms will go well beyond the food industry with the renewed interest in solvent fermentations.

9.0 FERMENTATION

Fermentation is a metabolic process that converts sugar to acids, gases or alcohol. It occurs in bacteria and yeast as well as in muscle cells that are oxygen-starved, as in the case of lactic acid fermentation. In a broader sense, fermentation refers to the large-scale cultivation of microbes on a growth medium, frequently to create a particular chemical product, such as an enzyme, an antibiotic, a vaccine, a food product or additive, etc. The science of zymology was founded by the French chemist Louis Pasteur, who in 1856 connected yeast to fermentation (Harrison and Solomon, 2024). Microorganisms use substrate substances throughout the fermentation process to carry out their metabolism, producing end by-products that can be used in a variety of sectors, including food, chemical, and pharmaceutical. Lactic Acid Bacteria (LAB) are one type of these microorganisms; they can be found as non-sporulating rods or cocci (Hayet *et al*., 2021).

9.1 Food Fermentation's Significance

The significance of food fermentation includes the production of high-quality nutrients, improved organoleptic characteristics, food preservation and the production of antibiotics.

9.1.1 Improvement of the organoleptic characteristics

Foods that have undergone fermentation have improved texture, flavour, aroma, and organoleptic properties, all of which contribute to their increased appeal. Fermented foods have more significant organoleptic qualities than unfermented foods because of their higher acceptance rate (Wang *et al*., 2019).

9.1.2 provision of high-quality nutrients

It is well recognized that low-income populations' primary foods, such as grains, have inadequate nutritional content. Foods with improved digestibility and nutritional value have been linked to fermentation by lactic acid bacteria. Through the hydrolysis of polysaccharides, phytates, proteins, and lipids, enzymes such as amylase, lipases, proteases, and phytates alter the main dietary items (Hayet *et al*., 2021). During fermentation, the ant nutrient factors (ANFs) in the food decrease while the amount, quality, and concentration of water-soluble vitamins rise. As a result, minerals including zinc, calcium, phosphorus iron, and amino acids have higher bioavailability (Fuerst, 2014).

9.1.3 Preservative properties

Studies have indicated that local fermentation contributes to the preservation of fermented foods like fruits and cereals. This results in the creation of acid, which lowers the pH level (Hayet *et al*., 2021). The acid generated keeps food from spoiling and causing food poisoning by preventing the growth of harmful bacteria. This extends the shelf life of fermented foods. As a result, the meals are safe for customers to transport, store, and stabilize (Chen, 2023).

9.1.4 Production of antibiotics

The microbes that create lactic acid bacteria are unaffected by the antimicrobial compounds that they make, such as *bacteriocin a*nd p*eptides*, which have antibacterial activity against foodborne pathogens and germs that cause food rotting. Since lactic acid bacteria (LAB) alter the makeup of intestinal microorganisms and act as a deterrent to pathogenic enteric bacteria, lactic acid bacteria (LAB) fermentation is utilized to avoid diarrheal illness (Patel and Patel, 2022). They are used as a barrier against bacteria that are not acid tolerant, which are removed from the medium ecologically because they are sensitive to an acidic environment (Sharma *et al*., 2020).

9.1.5 Detoxification during fermentation

Foods become free of toxins like aflatoxin and fumonisin when microorganisms like bacteria, yeast, moulds, and viruses infest them. Utilizing lactic acid bacteria in fermentation is a gentler approach to detoxification because it maintains the nutritional content and flavour of food. It eliminates pollutants. Moreover, fermentation breaks down mycotoxins without negatively impacting food's nutritional value (Hayet *et al*., 2021).

9.1.6 Reduced duration of cooking

Foods that have been processed to eliminate any anti-nutrients will eventually be easier to prepare and cook, and the nutritious value of fermented foods like cereals and legumes will increase. This is primarily connected to ogi made from maize and fermented soybean products (Hayet *et al*., 2021).

9.1.7 Promotion of health

Fermented foods, such as yogurt or fermented milk, have health benefits because they include a lot of probiotic bacteria, which lower cholesterol levels in the blood. Enzymes are abundant in raw fermented meals, and the body requires them for adequate digestion and optimal utilization of the food. Research has indicated that Nigerian fermented carbohydrate meals, such as fufu and ogi, offer significant health benefits, making them valuable for managing both human and animal gastroenteritis (Hayet *et al*., 2021).

10.0 CLASSIFICATION OF FOOD FERMENTATIONS

Depending on what number of final products, there are two forms of fermentation. Single-end products are produced during homo fermentation, and Multiple end products are produced during hetero fermentation. Various end products are produced at the end of fermentation, and fermentation is classified into several categories based on the types of end products produced (Ezemba and Ezemba, 2022).

10.1 Lactic Acid Fermentation

Glucose and other sugars with six carbon atoms undergo a process called lactic acid fermentation, which produces the metabolite lactate and cellular energy. Anaerobic fermentation of this kind usually takes place in bacteria, some animal cells, mammalian red blood cells, and occasionally in skeletal muscle when there is not enough oxygen available to support aerobic respiration. During this process, pyruvate from glycolysis is converted to lactic acid, NAD+ is formed from NADH, and lactate from anaerobic respiration during exercise builds up in the cell to cause exhaustion (Steinkraus, 2019). Lactic acid is created when the pyruvate from glycolysis goes through a straightforward redox process. It is distinct from other respiration processes since it is the only one that doesn't release a gas as a by-product. In all, one glucose molecule (or any six-carbon sugar) is converted to two molecules of lactic acid in equation 2.8 (Ezemba and Ezemba, 2022).

$$C_6H_{12}O_6 \rightarrow 2CH_3CHOHCOOH \quad (1)$$

10.2 Alcohol Fermentation

Alcohol fermentation is referred to as ethanol fermentation as ethanol is the end product. The fermentation of simple carbohydrates into carbon dioxide and ethanol is mostly carried out by yeast. It's often used in industries to produce wine, beer, and other goods like biofuel. During this process, pyruvic acid is transformed into acetaldehyde and carbon dioxide is released. Ethanol is created as acetaldehyde in this way. As it moves on to glycolysis, NADH is changed into NAD+. Two enzymes catalyse the two steps of the process. They are pyruvic acid decarboxylase and alcohol dehydrogenase (Steinkraus, 2019).

10.3 Acetic Acid/Vinegar Fermentation

Acetic acid is a component of the fermentation process used to make vinegar. The two-step procedure consists of the following steps: Using yeast, ethyl alcohol is made anaerobically from sugar. Acetobacter is a process of aerobic respiration that oxidizes ethyl alcohol to create acetic acid. Foods or condiments produced from acetic acid fermentations are generally harmless. Depending on the concentration, acetic acid can potentially have bacteriostatic or bactericidal effects. Acetic acid is typically present in palm wines and kaffir beers along with ethanol. A more preservative than ethanol is acetic acid. Cucumbers and other vegetables can be preserved and pickled with vinegar, which is a perfectly acceptable condiment. The fermentation of acetic acid and alcohol can be employed to guarantee food safety in different contexts (Deenanath *et al*., 2020).

10.4 Butyric Acid Fermentation

Butyric acid fermentation is only carried out by spore-forming, anaerobic bacteria that belong to the Clostridium genus, because, depending on the species performing the process, n-butanol, acetic acid, ethanol, isopropanol, and acetone are generated in addition to butyric acid, it is known as mixed acid fermentation. This type of fermentation is used to carry out the following processes: Ratting of jute fibre, Rancid butter, Tobacco processing and Tanning of leather (Ezemba and Ezemba, 2022).

10.5 Alkaline Fermentations

Many essential foods and condiments found in Africa are utilized not just to add taste to soups and stews but as inexpensive sources of protein for diet, these include the Nigerian dish dawadawa, the Ivory Coast soumbara, and the West African dish iru, which is prepared by fermenting cooked, soaked locust bean seeds (*Parkia biglobosa*) using bacteria from the genus *Bacillus*, usually *Bacillus subtilis*. *Citrullus vulgaris* seeds are used to make Nigerian ogiri, while oil beans (*Pentacletha macrophylla*) are used to make Nigerian ugba, sesame seeds (*Sesamum indicum*) are used to make Sierra Leonean ogiri-saro, castor bean (*Ricinus communis*) seeds are used to make Nigerian ogiri-igbo and fluted pumpkin bean (*Telfaria occidentale*) seeds are used to make Nigerian ogir-nwan. Soybeans can be substituted for locust beans (Steinkraus, 2019).

11.0 FACTORS AFFECTING TRADITIONAL FOODS' FERMENTATION PROCESS

11.1 Aeration and Agitation

Aeration is a crucial element that influences numerous components' fermentation processes. The Custer effect, which prevents growth in anaerobic environments, or the Pasteur effect, which prevents fermentation in aerobic environments, could be the results. *S. cerevisiae* significantly suppresses *D. bruxellensis* in batch fermentations under aerobic conditions (Abbasiliasi, Tan, Tengku Ibrahim, *et al*., 2017). The final ethanol yield decreases when there is considerable aeration. In the process, ethanol evaporates when gas exchange is not controlled, yeast breaks down ethanol in the presence of air, or yeast produces acetic acid instead of alcohol. Since aeration causes the synthesis of acetic acid, which may impact the overall yield of ethanol, limiting air is a superior fermentation setting for high-quality product production (Mengesha *et al*., 2022).

11.2 Temperature

The microbe has an ideal temperature range within which it can grow, making temperature a crucial component of microbial growth. A temperature differential may even have a significant co-effect with some of the other variables. The maximum fermentation time decreased with increasing temperature, but a much higher temperature inhibited cell growth and subsequently significantly decreased fermentation because it alters the transport activity or saturation level of soluble compounds and solvents in the cells, potentially increasing the accumulation of toxins like ethanol inside the cells. Conversely, the cells showed decreased specific growth rates at lower temperatures, which may have resulted from their low-temperature tolerance for ethanol (Bordoloi and Ganguly, 2019).

11.3 pH

The element of pH has the potential to impact both ethanol yield and cell development. Since yeast is not exposed to harsh environments, the impact on growth is most likely caused by variations in the toxicity of hydrolysate by-products rather than a simple pH effect. The primary fermentation pathway may be used in response to modifications in the functional pH of the ethanol generation process. A pH range of 4.0 to 5.0 must be maintained; if it is higher, the synthesis of by-products like acetic and butyric acid may have consumed some of the substrates, reducing the efficiency of ethanol fermentation (Abbasiliasi, Tan, Tengku-Ibrahim, *et al*., 2017).

11.4 Substrate Type and Salt Concentration

Depending on the substrates, several fermentation patterns emerged. Maltose and glucose were the primary fermentable sugars in barley wheat and wheat-red sorghum-injera, with a brief accumulation of maltose (Mengesha et al., 2022). Because lactic acid bacteria are known to withstand high salt concentrations, they have an advantage over non-salt-tolerant microorganisms in terms of proliferation. Because *Leuconostoc sp*. has a high tolerance to salt, it is recognized to be the primary initiator of lactic acid fermentations (Hayet *et al*., 2021).

11.5 Nutrients

Nutrients are necessary for all microbes to perform their metabolic functions. Substrates such as simple (like glucose) or complex (like starch) carbohydrates are needed for fermentation. Due to their high energy needs, these bacteria will develop more slowly if the quantity of substrate available is limited (Abbasiliasi, Tan, Tengku-Ibrahim, *et al*., 2017).

12.0 CHALLENGES IN AGRO-BASED SUBSTRATE FOR METABOLITES PRODUCTION

When using bacteria to create metabolites from fruit extracts or substrates, there are several significant challenges and limitations. One significant problem is that a lot of fruits include naturally occurring inhibitory chemicals such as organic acids, phenolics, and tannins that may have a detrimental effect on the target microorganism's growth and metabolic processes (Cuadrado-Osorio et al., 2022). These inhibitory effects may result in reduced biomass formation, altered metabolic pathways, and ultimately lower yields or compromised quality of the target metabolite. Furthermore, fruit-based substrates are often prone to contamination by indigenous or opportunistic microorganisms, which can compete with the production strain for nutrients, alter the fermentation profile, or introduce undesired metabolites, thus complicating process control and product purification (Alfonzo *et al*., 2020).

Cost-effectiveness, scalability, and biological concerns are major challenges. Using fruit-based substrates can be both economically attractive and practically feasible at the laboratory level; however, it is far more challenging to adapt these processes to continuous production on an industrial scale (Soccol *et al*., 2017). Variations in substrate composition, seasonal availability, and the perishable nature of fruits can all significantly affect production costs and process reliability (Pathak *et al*., 2018).

Moreover, ensuring consistent substrate quality, maintaining sterility, and mitigating microbial competition at scale often necessitate substantial investments in preprocessing, bioreactor design, and downstream processing (Pandey *et al*., 2000). Consequently, although fruit-based substrates offer a sustainable and low-cost alternative for microbial metabolite production in controlled laboratory settings, achieving industrial viability requires overcoming both biological and logistical barriers (Cuadrado-Osorio et al., 2022).

The seasonal production of agro-based substrates is one of the major challenges facing the production of metabolites along with its astringent and acrid principles. Agro-based substrates are difficult to store since they might decay totally within a few hours of harvest due to their perishable nature. Furthermore, its extreme susceptibility to injury restricts its value by causing microbial deterioration during harvest (Ketaki *et al*., 2020).

Pest infestation from fruit flies, thrips, and nut borers limits the use of agro-based substrates in product development. Second, microbiological illnesses are caused by the sensitive skin of some fruit. The third aspect is the physiology of the fruit, which includes a sharp decrease in volatile organic compounds and the rate of ethylene release at the postharvest stage. A sudden increase in abscisic acid at the pedicel and all over the fruit at the later stage of the development tends to reduce the retention capacity and firmness (Niveditha *et al*., 2024).

The problems that contribute to continuous underutilization, according to UNIDO, is the absence of commercial production equipment and processing technology. Inadequate knowledge about the fruit's long-term economic advantages and commercial potential contributes to its underutilization (Aluko, 2023).

13.0 FUTURE PERSPECTIVE

Utilizing microbes to generate beneficial metabolites from agro-based substrates has a lot of promise, especially when taking the circular economy and sustainable biotechnology models into account. One example of an increasing use is the production of bioactive chemicals, such as organic acids, antibiotics, enzymes, pigments, and biopolymers, which have a variety of uses in the food, cosmetic, pharmaceutical, and bioenergy industries (Li *et al*., 2021; Sadh *et al*., 2018). The variety of metabolites that can be effectively produced, even from diverse, inexpensive agricultural residue, is being further increased by developments in metabolic engineering and synthetic biology. A deeper understanding of microbial metabolism improved strain improvement techniques, and bioprocess optimization for increased yields and product specificity are all made possible by the integration of omics technologies (genomics, proteomics, and metabolomics) (Zhang *et al*., 2022).

Future research should focus on several key areas to fully harness the potential of agro-based substrates. First, there is a need to explore and characterize a broader diversity of microorganisms, particularly extremophiles and novel strains capable of tolerating the inhibitory compounds naturally present in agro-residues. Second, developing pre-treatment methods that can detoxify substrates without significantly increasing process costs will be critical. Research into co-cultivation strategies, where multiple microbial species synergistically enhance metabolite production, also represents a promising avenue. Moreover, scalable bioprocess designs that can handle seasonal variability and compositional heterogeneity of agro-based feedstocks must be prioritized. Finally, techno-economic analysis and life cycle assessment studies are necessary to guide the commercial translation of these technologies towards truly sustainable and economically viable industrial processes.

14.0 CONCLUSION

This review article highlights the importance of primary and secondary metabolites from a variety of sources, including microorganisms (bacteria, actinobacteria, and fungi) and plants, as well as their production, classification, use in different industries, and factors that affect metabolite production. In addition, it also focuses more on the fermentation of agro-based substrates, food fermentation classification, factors influencing the fermentation process of traditional foods, agro-based substrates and metabolites derived from them and challenges in using agro-based substrates for metabolite production. Primary metabolites, as previously established, are growth-dependent metabolites that are created by a variety of microbial systems (wild or engineered strains) through a variety of fermentation processes. Additionally, secondary metabolites are produced during the late stationary phase of growth and are not growth-dependent. Compared to secondary metabolites, primary is produced in large quantities and has a lower value added. Secondary metabolites, on the other hand, are much larger molecules and high-value, low-volume bioproducts.

A range of metabolic pathways and genetic engineering techniques are now employed to improve the efficiency of microbial systems and their ability to generate more primary and secondary metabolites with greater output and productivity. Bacterial yeast and some fungal species biosynthesize primary metabolites in different amounts, depending on the fermentation circumstances. Certain fungal strains and bacterial cells, however, are more efficient for secondary metabolites.

15.0 RECOMMENDATION

It is advised that sufficient attention be paid to the cultivation and use of microbial and agro-based metabolites due to their many benefits and the presence of vital chemicals, acids, phytochemicals, bioactive compounds, antioxidants, and other substances utilized in the food, pharmaceutical, and other related industries.

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3. REFERENCES

Abbasiliasi, S., Tan, J. S., Tengku-Ibrahim, T. A., Bashokouh, F., Ramakrishnan, N. R., Mustafa, S., and Ariff, A. B. (2017). Fermentation factors influencing the production of bacteriocins by lactic acid bacteria: A review. *RSC Advances*, *7*(47), 29395–29420. https://doi.org/10.1039/c6ra24579j

Alfonzo, A., Francesca, N., Sannino, C., Settanni, L., and Moschetti, G. (2020). Microbial dynamics during the production of traditional fermented foods and beverages. *Food Research International*, 129, 108837. https://doi.org/10.1016/j.foodres.2019.108837

Aluko, A. (2023). Underutilized Cashew Apple Fruit : Its Utility and Development as a Source of Nutrients and Value Added Products in Tanzania. *Life Science and Bio-Engineering*, *11*, 719–734.

Amin, A., Zhang, Q., and Yang, Z. (2021). Acetic acid and its health benefits: A review. *Frontiers in Nutrition, 8*, 601581. https://doi.org/10.3389/fnut.2021.601581

Azeez, A. O. K. and A. K. (2019). Beneficial Role of Microorganisms. *Journal of Chemical Engineering, 5*, 71–90.

Bertazzoni, S., Voci, S., and Chianese, L. (2021). Amino acids and their applications in food and health. *Foods, 10*(8), 1906. https://doi.org/10.3390/foods10081906

Bordoloi, R., and Ganguly, S. (2019). Chemical Regulatory Factors Influencing the Process of Biofermentation of Food: A Review. *Journal of Biological and Chemical Research*, *31*(1), 6–11

Cai, R., Li, Y., Zhang, Z., and Zhang, M. (2021). Selection of fermentation microorganisms for production of functional metabolites. *Journal of Microbiology and Biotechnology, 31*(8), 1065–1075. https://doi.org/10.4014/jmb.2103.03040

Chen, X., et al. (2022). Temperature-driven metabolic shifts in Pseudomonas putida for bioplastic production. *Metabolic Engineering*, 74, 12–22.

Chen, Z. (2023). Role of Microorganisms and Enzymes in Fermentation Journal of Food : Microbiology, Safety and. *Journal of Food: Microbiology, Safety and Hygiene*, *8*(4), 1–2. https://doi.org/10.35248/2476-2059.23.8.225.Citation

Choi, K. R., et al. (2022). CRISPR-based metabolic engineering of microorganisms for biofuels and biochemicals. *Nature Reviews Microbiology*, 20(5), 321–337.

Cuadrado-osorio, P. D., Ramírez-mejía, J. M., Mejía-avellaneda, L. F., Mesa, L., and Bautista, E. J. (2022). Bioresource Technology Reports Agro-industrial residues for microbial bioproducts : A key booster for bioeconomy. *Bioresource Technology Reports*, *20*, 1–13.

Deenanath, E. D., Rumbold, K., and Iyuke, S. (2020). The Production of Bioethanol from Cashew Apple Juice by Batch Fermentation Using Saccharomyces cerevisiae Y2084 and Vin13. *ISRN Renewable Energy*, *2013*, 1–11. https://doi.org/10.1155/2013/107851

Elshafie, H. S., Camele, I., and Mohamed, A. A. (2023). A Comprehensive Review on the Biological, Agricultural and Pharmaceutical Properties of Secondary Metabolites Based-Plant Origin. *International Journal of Molecular Sciences*, *24*(4), 1–20. https://doi.org/10.3390/ijms24043266

Ezemba, C. C., and Ezemba, A. S. (2022). Fermentation, Types Of Fermenters, Design and Uses Of Fermenters and Optimization Of Fermentation Process Fungal Quality of Fresh Shrimp View project Econometric and Non-parametric View project. *Food Microbiology*, *6*(4), 1–25. https://www.researchgate.net/publication/358265321

Francesca, I., Mera, G., Estefanía, D., Falconí, G., and Córdova, V. M. (2019). Secondary metabolites in plants : main classes, phytochemical analysis and pharmacological activities. *Chemical Sciences and Engineering.*, *4*, 1000–1009.

Fuerst, J. A. (2014). Microorganisms is a journal of unifying concepts for the science of microbiology.pdf. *Open Access*, *2*, 140–146. https://doi.org/10.3390/microorganisms2040140

Gallardo, E., and Seca, A. M. L. (2022). Secondary Metabolites and Their Applications. *Applied Sciences (Switzerland)*, *12*(5), 1–5. https://doi.org/10.3390/app12052317

Gao, C., et al. (2021). Fed-batch strategies for microbial metabolite production: Trends and applications. *Biotechnology Advances*, 50, 107768.

Gómez-Estaca, J., Rodríguez-Nogales, J. M., and Sánchez-Rodríguez, A. (2020). Bioactive compounds from fruit and vegetable by-products as antioxidant, anti-inflammatory and antimicrobial agents: A review. *Journal of Food Science, 85*(6), 2179–2191. https://doi.org/10.1111/1750-3841.15210

Guerriero, G., Berni, R., Muñoz-Sanchez, J. A., Apone, F., Abdel-Salam, E. M., Qahtan, A. A., Alatar, A. A., Cantini, C., Cai, G., Hausman, J. F., Siddiqui, K. S., Hernández-Sotomayor, S. M. T., and Faisal, M. (2018). Production of plant secondary metabolites: Examples, tips and suggestions for biotechnologists. *Genes*, *9*(6), 1–22. https://doi.org/10.3390/genes9060309

Harrison, A., and Solomon, B. O. (2024). School of Bio and Chemical Engineering Department of Biotechnology Unit : Microbiology and Cell Biology-Sbta1103. *Journal of Food Engineering*, *10*(4), 130–187.

Hayet, S., Sujan, K. M., Mustari, A., and Miah, M. A. (2021). Mato-biochemical profile of turkey birds selected from Sherpur district of Bangladesh. *Int. J. Adv. Res. Biol. Sci*, *8*(6), 1–5. https://doi.org/10.22192/ijarbs

Hussain, M. S., Fareed, S., Ansari, S., Rahman, M. A., Ahmad, I. Z., and Saeed, M. (2020). Current approaches toward production of secondary plant metabolites. *Journal of Pharmacy and Bioallied Sciences*, *4*(1), 10–20. https://doi.org/10.4103/0975-7406.92725

Irchhaiya, R., Kumar, A., Yadav, A., Gupta, N., Kumar, S., Gupta, N., Kumar, S., Yadav, V., Prakash, A., and Gurjar, H. (2021). Metabolites in Plants and Its Classification. *World Journal of Pharmacy and Pharmaceutical Sciences*, *4*(1), 287–305.

Javed, M. R., et al. (2023). Adaptive laboratory evolution for industrial strain improvement. *Trends in Biotechnology*, 41(2), 150–165.

Kallscheuer, N., Classen, T., Drepper, T., and Marienhagen, J. (2019). Production of plant metabolites with applications in the food industry using engineered microorganisms. *Current Opinion in Biotechnology*, *56*, 7–17. https://doi.org/10.1016/j.copbio.2018.07.008

Ketaki, B., Vaishali, A., and Amit, A. (2020). Review Article Anacardium Occidentale by-Product : A Review on Sustainable Application and Added Value. *Journal of Food Nutrition and Metabolism*, *3*, 1–6. https://doi.org/10.31487/j.JFNM.2020.01.04

Kumar, A., Yadav, A., Gupta, N., Kumar, S., Gupta, N., Kumar, S., Yadav, V., Prakash, A., and Gurjar, H. (2021). World Journal of Pharmacy and Pharmaceutical Sciences metabolites in plants and its classification. *World Journal of Pharmacy and Pharmaceutical Sciences*, *4*(1), 2278–4357. www.wjpps.com

Kumar, B., et al. (2023). Pretreatment of lignocellulosic biomass for microbial conversion. *Bioresource Technology*, 369, 128469.

Lee, S. Y., et al. (2023). *Smart bioreactors: Real-time monitoring and control for metabolite production*. ACS Synthetic Biology, 12(4), 1023–1035.

Li, M., Xu, C., Wang, L., Zhao, J., and Zhang, H. (2021). Recent advances in metabolic engineering of microorganisms for production of value-added products from agro-industrial waste. *Biotechnology Advances*, 47, 107683. https://doi.org/10.1016/j.biotechadv.2020.107683

Liu, Y., et al. (2023). Dynamic regulation of secondary metabolism in Streptomyces. *Current Opinion in Biotechnology*, 80, 102902.

Martinez, V., et al. (2021). Oxygen-limited fermentation for enhanced antibiotic production. *Applied Microbiology and Biotechnology*, 105(14), 5783–5795.

Mengesha, Y., Tebeje, A., and Tilahun, B. (2022). A Review of Factors Influencing the Fermentation Process of Teff (Eragrostis teff) and Other Cereal-Based Ethiopian Injera. *International Journal of Food Science*, *2022*, 1–10. https://doi.org/10.1155/2022/4419955

Müller, C. G., Pinto, M. L., and Pereira, S. G. (2017). Citric acid production and its industrial applications. *Journal of Industrial Microbiology and Biotechnology, 44*(3), 395–402. https://doi.org/10.1007/s10295-017-1927-4

Niveditha, C., Veena, B. M., and Shweatha, H. E. (2024). Formulation of cashew apple-based products for nutrition-centric sustainability. *International Journal of Science and Research Archive*, *12*(01), 2169–2178 https://doi.org/doi.org/10.30574/ijsra.2024.12.1.0958

Nwaiwu, O., and Ibekwe, V. I. (2021). Natural inhibitors in plant materials: Implications for microbial fermentation and industrial applications. *Journal of Microbial Biotechnology*, 31(4), 425–437. https://doi.org/10.1111/1751-7915.13776

Ofoedum, A. F., Uyanwa, N. C., Chikelu, E. C., Iroagba, L. N., Ugwoezuonu, J. N., and Anaeke, E. J. (2024). Primary and Secondary Metabolites as Products of Microbial Metabolism : Uses and Application in Foods, Pharmaceutical and Allied Industries. A Review. *European Journal of Applied Science, Engineering and Technology*, *2*(2), 4–16. https://doi.org/10.59324/ejaset.2024.2(2).01

Omar, S. A., El-Kady, M. F., and El-Ghandour, M. (2020). Ethanol production from cashew apple juice: A sustainable approach. *Renewable Energy, 147*, 1557–1564. https://doi.org/10.1016/j.renene.2019.09.032

Ozyigit, I. I., Dogan, I., Hocaoglu-Ozyigit, A., Yalcin, B., Erdogan, A., Yalcin, I. E., Cabi, E., and Kaya, Y. (2023). Production of secondary metabolites using tissue culture-based biotechnological applications. *Frontiers in Plant Science*, *14*(4), 1–28. https://doi.org/10.3389/fpls.2023.1132555

Pandey, A., Soccol, C. R., and Mitchell, D. (2000). New developments in solid-state fermentation: I—Bioprocesses and products. *Process Biochemistry*, 35(10), 1153–1169. https://doi.org/10.1016/S0032-9592(00)00152-7

Paschapur, A., Singh, A. K., Jeevan, B., Stanley, J., Rajashekhar, H., and Mishra, K. K. (2021). Unraveling the Importance of Metabolites from Entomopathogenic Fungi in Insect Pest Management. *Chemical Industry and Chemical Engineering Quarterly*, *2*, 89–120. https://doi.org/10.1007/978-3-030-67231-7_5

Patel, R. A., and Patel, Y. I. (2022). Microbial fermentation and its role in quality improvement of fermented foods. *Journal of Emerging Technologies and Innovative Research (JETIR)*, *9*(7), 203–209.

Pathak, P. D., Mandavgane, S. A., and Kulkarni, B. D. (2018). Fruit waste valorization through microbial processes: Sustainable perspectives. *Bioresources and Bioprocessing*, 5(1), 1–15. https://doi.org/10.1186/s40643-018-0218-0

Reid, A. E., Houghton, R. A., and McLoughlin, P. (2016). Amino acids in human nutrition and health. *Food Chemistry, 192*, 92–97.

https://doi.org/10.1016/j.foodchem.2015.07.097

Riaz, M., Khan, A. A., and Iqbal, M. (2018). Antioxidant and antimicrobial properties of tannins: A review. *Food Science and Nutrition*, *6*(5), 1123–1131. https://doi.org/10.1002/fsn3.714

Sadh, P. K., Duhan, S., and Duhan, J. S. (2018). Agro-industrial wastes and their utilization using solid-state fermentation: a review. *Bioresources and Bioprocessing*, 5(1), 1–15. https://doi.org/10.1186/s40643-017-0187-z

Sharma, P., et al. (2022). Agro-waste valorization for microbial metabolite production. *Renewable and Sustainable Energy Reviews*, 158, 112195.

Sharma, R., Garg, P., Kumar, P., Bhatia, S. K., and Kulshrestha, S. (2020). Microbial Fermentation and Its Role in Quality Improvement of Fermented Foods. *Journal of Fermentation*, *3*(1), 1–20.

Steinkraus, K. H. (2019). Fermentations in World Food Processing. *Comprehensive Reviews in Food Science and Food Safety*, *1*, 23–32. https://doi.org/10.1097/01209203-200503000-00001

Tariq, A., Zubair, M., and Aslam, M. (2020). Industrial applications of microbial enzymes: A review. *Applied Biochemistry and Biotechnology*, *192*, 1372–1386. https://doi.org/10.1007/s12010-020-03394

Thirumurugan, D., Cholarajan, A., Raja, S. S. ., and Vijayakumar, R. (2020). An Introductory Chapter: Secondary Metabolites. *Secondary Metabolites - Sources and Applications*, *5*(2), 1–20. https://doi.org/10.5772/intechopen.79766

Wang, L., et al. (2021). Nitrogen regulation of antibiotic biosynthesis in actinobacteria. *Frontiers in Microbiology*, 12, 656610.

Wang, S., Alseekh, S., Fernie, A. R., and Luo, J. (2019). The Structure and Function of Major Plant Metabolite Modifications. *Molecular Plant*, *12*(7), 899–919. https://doi.org/10.1016/j.molp.2019.06.001

Zhang, C., Chen, X., and Liu, L. (2022). Systems metabolic engineering for biotechnological production of high-value chemicals from renewable resources. *Biotechnology Advances*, 59, 107988. https://doi.org/10.1016/j.biotechadv.2022.107988

Zhang, Y., et al. (2021). Metabolic engineering of Aspergillus niger for citric acid overproduction. *Microbial Cell Factories*, 20(1), 1–15