

Microbiomics Research Applications

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Abstract: *Microbiomics is a growing scientific field focusing on the quantification, characterization, and functional determination of complex microbial communities. Microbiomics utilizes microbiology, molecular biology, and bioinformatics analysis to study the composition of microorganisms and the inner workings of microbial populations in a distinct habitat and to assess microbe - derived genomic signatures, proteins, and metabolites. The current review examines microbiome research literature and extracts critical evidence highlighting current and potential benefits and applications of microbiome investigations in medicine, agriculture, and biotechnology. It focuses on how metatranscriptomic and metabolomic techniques have identified key molecules and mechanisms that have expanded our understanding of how microbial communities function in their natural ecosystem. Additional microbiomics research will continue to uncover essential microbial molecules and pathways of societal significance.*

Keywords: microbiome; bioprocessing; metabolomics; biotechnology; translational

1. Introduction

The microbiome refers to all the microorganisms and their associated genetic material in a specific ecosystem. Microbiomes are all around us and form virtually invisible communities of trillions of symbionts that facilitate the overall functioning of a unique ecosystem [1]. While there are many unresolved issues regarding microbial community convergence, new technologies such as metagenomics, metatranscriptomics, and metabolomics have open avenues for gaining a more comprehensive understanding of the functional features of microbes and provided insight into novel molecules and crosstalk mechanisms among microorganisms [2]. Metagenomics involves the detection of microbial genomic signatures in a particular ecosystem. Metatranscriptomics provides an assessment of gene expression at the microbial level. Metabolomics employs liquid chromatography - mass spectrometry to identify metabolites, signaling molecules, various hormones, and metabolic pathways critical to the dynamics of plant, animal, and microbial physiology [3 - 8]. Both metagenomics and metatranscriptomics employ whole genome sequencing protocols for DNA and RNA, respectively. Elucidation of not only the composition of microbes in an environment and the discovery of novel molecules will open the door to immense breakthroughs in medicine, agriculture, biotechnology, and other industries (e. g., bioprocessing, pharmacological) [9].

2. Microbiomics and Medicine

At present, metabolomics is currently clinically applied in the diagnosis of healthy and non - healthy patients. Microbial metabolome profiles establish baselines and abnormal limits of physiological modulators. Metabolomics and metatranscriptomics provide a global strategy to evaluate potential biomarkers for several infectious diseases in humans. Clinicians can use microbiomic technologies to monitor phenotypic responses in biofluids to various drug regimens to promote life - saving clinical decisions. Moreover, since metatranscriptomics provides insights into functional microbial gene expression, microbiologists can

decipher pathogenic responses to anti - microbial treatments at the transcriptional level.

Investigators recently subjected the fecal microbiome to chromatography - mass spectrometry metabolic profiling protocols to assess alterations in microbial metabolites for early - onset Alzheimer's disease, Alzheimer's disease, and unaffected healthy patients [10]. A dysfunctional tryptophan metabolic pathway was detected during Alzheimer's disease progression. Specifically, the metabolic products DL - 5 - methoxytryptophan and indole - 2 - carboxylic acid were significantly reduced in Alzheimer's patients versus healthy control study participants. Supplementation with these specific molecules or other metabolites may be beneficial to slow down or reverse cognitive decline. These types of investigations are becoming more common and have the potential to form the basis of effective diagnostic practices and therapeutic solutions.

Microbial metabolomics is more valuable than metatranscriptomics from a therapeutic value standpoint because the metabolome, unlike the transcriptome, is a much better indicator of organismal phenotype. Food allergies are prevalent and constitute a global problem. Understanding how the microbial metabolome contributes to food allergies provides another example of how studying microorganism - derived metabolic intermediates and pathways can affect the medical field and clinical practice. Bao et al. [11] analyzed two human cohorts (e. g., food allergy, no food allergy). They found no difference in microbial diversity using 16s rRNA amplicon sequencing. Still, they observed a higher abundance of diacylglycerol in healthy participants, suggesting that this molecule could be a useful biomarker for food allergies.

Granata et al. [12] explored the human and microbial transcriptome in severely obese patients. They demonstrated that in obese patients compared to healthy lean control patients, microbial genes that play a role in deregulating biomolecular pathways (e. g., carbohydrate, protein, and lipid) were significantly different. Research observations point to clear, achievable applications of microbial

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metabolomics and microbial metatranscriptomics in diagnosing infectious and non - infectious diseases, characterizing different disease stages, measuring physiological responses to surgical treatments, and isolating key regulator molecules that could serve as potential treatments of human disease [13]. Moreover, microbial metabolomics and metatranscriptomics establish operational strategies for personalized medicine, where a patient's metabolome and transcriptome data assist in developing specific treatment plans. Developing individual - specific prebiotics and probiotics diet plans to mitigate morbidity and mortality is also achievable using microbiome research data.

3. Microbiomics and Agriculture

Many agricultural applications are in effect following increased microbiome - based research investigations [14]. Experimental insights gleaned from plant - focused studies have uncovered many symbiotic microbes, microbial genes, and microbial and plant metabolites that may address food insecurity issues by creating sustainable strategies to enhance the nutritional value of food crops, reduce plant susceptibility to plant pathogens and abiotic stress, and improve the number of essential crops generated globally.

Studying novel microbial genes will determine their efficacy in breeding protocols to produce better crop yields. Malik et al. [15] performed a ten - year experiment to examine the plant microbiome shift associated with drought conditions to determine how subpopulations of microbes respond to water loss over a long period. They demonstrated that over time there is a discernible formation of taxonomic groups with the ability to utilize various substances to control osmoregulatory processes and to construct extracellular molecules that enhance the plant's water retention capabilities.

The critical analysis of the underlying mechanisms mediated by plant - associated microbes to support plant survival during abiotic stressors like droughts will shed light on novel agricultural strategies to fight against harmful environmental events. Moreover, the biochemical isolation and analysis of extracellular molecules produced by microbes during stressful conditions will point to improved materials and approaches to protect plants. It is becoming increasingly clear that distinct phytomicrobiome communities offer promising applications in developing sustainable and eco - friendly agricultural products and practices. Burrage and Jeon [16] recently reviewed the state of endosphere research concerning contemporary and future beneficial translational applications of microbes and their genotypic and phenotypic products. The production and application of synthetic microbial communities (SynComs) in agriculture is promising and has proffered consistent proficuous results to sustainably alleviate and prevent both biotic and abiotic stress in plants [17].

4. Microbiomics and Biotechnology

Biotechnology applications use microbes, microbial structures, and microorganism - mediated mechanisms to produce outcomes that benefit humankind. Data reviewed in this section addresses recent biotechnological and industrial

uses of microbes or the molecules that microbes make to enhance existing commercial or pharmaceutical processes. Whole - genome sequencing technology applied to microorganisms has impacted the biotechnology industry and produced exciting discoveries in the past few years. Regarding metabolomics, isolating key small molecules could replace the need for specialized enzymes and protein expression systems in industrial applications.

Examination of microbiomes in diverse environments has been instrumental in identifying unique microenvironments that are analogous to industrial bioreactors in terms of producing relevant compounds for various commercial applications. Microbial chain elongation is an essential industrial technique for producing complex carboxylates for downstream bioprocessing, biotechnological, and pharmaceutical applications [18]. Investigating microbiomes using 16S rRNA gene sequencing and other culture - independent techniques has also elucidated critical microbes, taxonomic groups, and underlying metabolic pathways that play crucial roles in microbial chain elongation [19 - 20]. Contreras - Dávila et al. [21] demonstrated that sunflower oil when used as a solvent during microbiome - based bioprocessing reactions, can enhance production rates and lower toxicity levels of microbially produced medium - chain carboxylates and promote downstream utilization of the chemical products in myriad industrial and commercial applications.

Complex microbial communities associated with ruminant animals possess an array of functional qualities that may be of interest to biotechnology and bioprocessing companies, from developing more effective waste removal systems to developing sustainable energy and biofuels. Researchers recently explored the fungal and bacteria microbiome in the goat digestive tract [22].

The experiment elucidated microbiota elements responsible for lignocellulose digestion and assimilation using sequence and metabolic reconstruction data. Using bioinformatics software to assemble probable microbe - specific metabolic pathways allows researchers to predict potential bioprocessing phenotypes better. Results demonstrated that fungi are prevalent in converting lignocellulose into other chemical compounds. Exploration of the genomic structure of dominant microbes from diverse environments can lead to the isolation and characterization of unique genes that may benefit industrial processes and implement real - world applications [23 - 24].

5. Conclusion

The applications of microbiome research are boundless. Microbiomics techniques that include microbial metatranscriptomics and metabolomics can significantly affect the biotechnology industry and supplement medical and agricultural practices. Moreover, the genetic engineering of critical microorganisms in humans and plants will create opportunities for biotechnological and agricultural discoveries and deliver microbe - specific medical treatments to clinicians and healthcare practitioners. The significant benefit of metabolomics is that this approach identifies actual metabolites and other biomolecules; thus,

this molecular assessment strategy most closely resembles the precise physiological phenotype of living organisms. Identifying essential microbial genes and metabolic molecules opens the door for detecting, isolating, enriching, restoring, and suppressing biomolecules to promote human health, increase crop production, and generate useful products for society. A commitment to future microbiome cross - disciplinary translational research studies will undoubtedly improve the microbiome research field and subsequently improve our world. Moreover, the increasing utilization and enhancement of microfluidics technologies and a focus on developing new insights to reduce chronic limitations in the technology will expedite our understanding of microbiomes [25 - 26]. Additionally, further studies involving microfluidics technology are needed to expand our knowledge of the functional attributes of the microbiome in humans and the environment.

Since microorganisms possess many metabolic properties and limitless genetic reservoirs, ideation possibilities are endless. Continued microbiome composition and functional studies are needed to explore aerobic and anaerobic microbes in their natural environments [27]. Moreover, investigating microbiome populations that cope with abiotic and biotic pressures needs more attention to identify molecules and pathways that may have value to humans. Further, microbiome exploration studies utilizing host organisms with exciting properties or unique ecological niches are of significant interest when you consider that microbial inhabitants facilitate host organisms' protection, maintenance, and survival. Future review articles will focus on specific industries (e. g., food industry, chemical processing) and present detailed examples of how data produced during a microbiome study enhances the state of the industry. Artificial intelligence platforms and sample automation systems will have profound and measurable effects on microbiome research and impact the translation of microbiome research findings into beneficial products.

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