

AYURVEDA AND THE HUMAN GUT MICROBIOME: BRIDGING TRADITIONAL CONCEPTS WITH MODERN MICROBIAL SCIENCE

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ABSTRACT:

The human gut microbiome is now coming into light that it plays a significant role in regulating digestion, metabolism, mucosal immunity, neuroendocrine signalling and systemic (whole-body) homeostasis. This review critically investigates the contemporary microbial science and the concept of Ayurvedic science like Agni, Ama, Prakriti, Dosha, Ojas, Ahara, Vihara and Srotas. These are not intended to be a direct representation of microbial taxa, metabolites, or biomarkers, but rather as organized, hypothesis-testing approaches to explore how digestive function, metabolic response, inflammatory susceptibility and physiological resilience vary among individuals. At present, there is evidence that the composition and/or function of the microbiota can be affected by dietary fibre; fermented foods; meal timing; physical activity; stress control and plant-derived bioactives. On the other hand, the bioavailability, pharmacological activity and safety of herbs can be altered by intestinal microorganisms, which would transform the herbs' components. The translation of the relationship between Prakriti phenotypes, Ayurvedic formulations and microbiome profiles further suggests link and emerging studies show promise but are limited by small study cohorts, heterogeneous interventions, inconsistent Prakriti phenotyping, and poor, short-term validation. The therapeutic applications are potential functional gastrointestinal disorders, metabolic disease, chronic inflammation, healthy ageing and gut–brain axis dysfunction. The standardization of the ayurvedic assessment, authentic formulations with chemical characterization, integrated metagenomics and metabolomics, clinical trials and patient-centred outcomes will be necessary for progress. But the most plausible is neither conceptual equivalence, but a scientifically testable systems-based model for personalized, preventive and adjunctive health care. This approach could ensure that traditional knowledge and practices are not lost while enhancing precision of mechanism of action, accountability in clinical practice, reproducibility and responsible interdisciplinary translation in various health care settings worldwide.

KEYWORDS: Ayurveda; gut microbiome; Agni; Prakriti; personalized healthcare

1. INTRODUCTION

The gut is an ever-changing microbial environment that plays an important role in the process of digestion, metabolism, immune regulation and systemic homeostasis. This ecosystem consists of bacteria, archaea, viruses, genes, metabolites and their interactions/relationships. The gut microbiome is not only made up of microorganisms, but also the functional environment created by the interactions between host and microbes. This expanded scope of definition has inspired studies of microbial functions, community stability, metabolite production and host–microbe communication as mediators of health and disease, in the place of cataloging microbial taxa (Berg et al., 2020).

Diet is one of the most alterable factors of the gut microbiome. Microbiological communities are involved in fermentation of non-digestible carbohydrates, biosynthesis of vitamins, bile acid and phytochemical metabolism, generation of short-chain fatty acids and regulation of the integrity of the intestinal barrier. These functions have an impact on gastrointestinal health, glucose regulation, lipid metabolism, inflammation and immune signalling. In humans, there are links between dietary patterns and the composition of microbes, metabolic capacity and cardio-metabolic markers across repeated dietary patterns. Alterations in the microbial and physiological responses can occur in individuals with identical diets, suggesting the need for personalized nutrition and dietary recommendations to be unique (Asnicar et al., 2021).

Controlled interventions are examples of the microbiome responsiveness to food based modulation. Diets rich in fermented food and rich in fibre have been linked to greater microbial diversity and less inflammatory activity, and effects

of high fibre intake might be related to the functional capacity of the microbiome (Wastyk et al., 2021). Diet also influences pro-inflammatory and anti-inflammatory microbial pathway. A diet composed of legumes, whole grain foods, fruits and vegetables, nuts and fish has been associated with beneficial microbial properties and highly processed diets have been associated with inflammatory microbial functions (Bolte et al., 2021). The results indicate that the microbiome does not simply mirror "what you ate last week" but rather it appears to reflect "what you have been eating over the past few months.

This evidence provides basis for the study of Ayurveda with the modern microbial science. Ayurveda sees health as a multidimensional phenomenon that involves digestion, metabolism, constitution, lifestyle, nutrition and immunity and the environment. Agni is the ability to absorb and transform the matter, Ama is the pathological matter, which is believed to be produced by the failure of Agni or disturbance of metabolic process. Prakriti refers to one's constitutional qualities, and the three Doshas (Vata, Pitta and Kapha) are patterns of regulation in physiology. In Ayurvedic Medicine, the principles of Ahara, Food Compatibility, Maitra, Timing of Meals, Seasonal Adaptation and Ahari Vriksha, Daily Routine all represent individualistic considerations of gastrointestinal health.

These traditional constructs should not be introduced as a direct comparison to microbial taxa, microbial metabolites, inflammatory markers or biomedical categories of disease. This would be oversimplification of the theory of Ayurveda and the biology of microbiome. One way to think about this is to consider the Ayurvedic concepts as hypotheses to be investigated with regard to digestive efficiency, host phenotype, microbial metabolism, barrier function and inflammatory regulation. This allows for interdisciplinary participation, and the maintenance of the conceptual integrity of the two knowledge systems.

Another interface with the gut microbiome is through medicinal plants or polyherbal formulations of the Ayurvedic medicine system. In the case of herbal medicines, there are many phytochemicals that could be affected by intestinal micro-organisms in terms of absorption, metabolism, bioavailability and biological activity. Herbal compounds in turn might affect the composition of microbes, their production of metabolites, and the signalling within the gut. This is a bidirectional connection, and the microbiome can be used as an intermediary of the pharmacology of herbs and a therapeutic target (An et al., 2019). The following is a relevant example as curcumin has intestinal and anti-inflammatory effects, which are not systemic due to its low bioavailability. These effects could be mediated by microbial transformation and/or microbiome modulation, which would need to be clarified (Scazzocchio et al., 2020).

The pre-clinical evidence suggests that Ayurvedic formulations have a microbiome modulating effect. However, a small randomized pilot study exploring the effects of supplementing with Triphala and Manjistha on the human gut microbiota suggests that it may be possible to affect the human gut microbiota, though with caution due to the exploratory nature and small sample size of this study (Peterson et al., 2020). In broader context, the therapeutics based on Ayurvedic principles need to be validated with authentic plant inputs, standardized formulations, reproducible production, mechanistic validation and clinical trial designs (Patwardhan, 2023).

This integration might be relevant throughout the life span. Aging is also associated with alterations of microbial diversity, stability, immune regulation and metabolic function that can lead to chronic inflammation, frailty, and decreased resilience (Bradley & Haran, 2024). The concept of tailoring diet and lifestyle, adaptation to seasonal changes, and the use of restorative practices in Ayurveda could be beneficial models for microbiome-driven healthy ageing, but these strategies require further investigation using clinical and multi-omics studies.

In this context the present review critically explores the correlation between Ayurvedic principles of digestion, constitution, diet, lifestyle and drug administration in herbal (Rasayana) medicine with the present understanding of human gut microbiome. It assesses conceptual interfaces, dietary influences, interactions with microbes and the potential for translation and sets aside the traditional interpretation from valid biological evidence. The balanced method of the review aims at ameliorating the scientific possibilities, limitations, and future relevance of combining the Ayurvedic knowledge with the modern microbial science in gastrointestinal, metabolic, immune and age-related health parameters.

2. Human Gut Microbiome: Composition, Development and Functional Significance

The human gut microbiome is a complex spatial ecosystem of bacteria, plus archaea, fungi, viruses, bacteriophages, their genes and metabolites. The density and types of microbes are different throughout the gastrointestinal tract due to differences in pH, oxygen levels, food transit time, exposure to bile, thickness of the mucous layer and nutrients present in each section. Generally, there are fewer microorganisms in the stomach and proximal small intestine, while dense anaerobic communities and fermentation are present in the colon. While Firmicutes, Bacteroidota, Actinobacteriota, Proteobacteria and Verrucomicrobiota are the most prevalent groups in the adult gut, there are differences at the genus, species and strain level between individuals. Thus, it is impossible to predict microbiome function from taxonomic structure alone; metabolic pathways, ecological interactions, metabolic redundancy and production of metabolites all play a major role.

The gut microbiome starts shaping early in life and is shaped by the type of delivery, infant feeding, maternal health, antibiotic use, family environment, location and, later, dietary changes. The human milk oligosaccharides and immune active compounds in breast milk enhance proliferation of beneficial organisms and the solid food intake increases the diversity of microbes and metabolic capacity. The microbiome is fairly stable in adults, but still influenced by diet, medications, infection, stress, sleep, exercise and changes in the environment. Ageing can impact on ecological stability and helpful metabolic processes, specifically if coupled with frailty, constrained diet and polypharmacy, and immune senescence. Table 1 outlines the main structural, developmental and functional characteristics of the microbiome of the human gut.

Table 1. Structural, Developmental, and Functional Attributes of the Human Gut Microbiome

Analytical domain	Key characteristics	Biological relevance
Microbial composition	Bacteria, archaea, fungi, viruses and metabolites	Supports digestion, metabolism and host signalling
Spatial organization	Low density in the upper tract; dense colon communities	Determines regional fermentation and metabolic activity
Lifespan development	Influenced by birth, diet, antibiotics and ageing	Shapes diversity, stability and immune maturation
Dietary modulation	Fibre, resistant starch, protein and fat	Alters microbial ecology and metabolite production
Microbial metabolites	SCFAs, bile acids and indole derivatives	Regulate immunity, barrier function and metabolism
Intestinal barrier	Mucus, epithelium, tight junctions and immune cells	Prevents microbial translocation and inflammation
Inter-organ communication	Gut–brain, gut–liver and metabolic axes	Influences neurological, hepatic and metabolic health
Dysbiosis	Disturbed microbial composition or function	Associated with gastrointestinal and systemic disorders

The structure and function of microbes is one of the most powerful modifiable factors influenced by diet. Complex carbohydrates and resistant starches promote saccharolytic fermentation while high protein fermentation may lead to the formation of potentially harmful metabolites like ammonia, phenols and branched-chain fatty acids. Fat in the diet may affect the secretion of bile acids and promote organisms that thrive in an environment of bile. But the effects of limiting carbohydrates, fat or protein on the microbes is not consistent. These are dependent on nutrient quality, replacement foods, length of intervention, baseline dietary patterns and the original microbial environment. The researchers conducted a systematic microbiome review of macronutrient restriction and identified significant variation in the response across the different macronutrients, suggesting that the nutritive and host context should be taken into account when assessing the microbiome response to a macronutrient restriction than by nutrient category only (Schoonakker et al., 2025).

One of the key roles of the gut microbiome is the fermentation of the foods which the human enzyme system cannot digest. This results in the production of short chain fatty acids such as acetate, propionate and butyrate. Acetate is used in peripheral metabolism, propionate is involved in hepatic metabolic regulation, and butyrate is used as an energy source by colonocytes and serves to stimulate mucus production, epithelial repair and the maintenance of the integrity of tight junctions. These metabolites also play a role in the activity of immune cells, appetite signalling, glucose regulation and gene expression. They are also paramount to the gut–brain axis where they can influence blood–brain barrier function, neuroinflammation, maturation of microglia, and pathways related to neurotransmitters (Dalile et al., 2019).

The intestinal barrier is the focal point between intestinal microbial communities and intestinal tissue. It is composed of epithelial cells, tight junctions, mucus, antimicrobial peptides, immunoglobulins and local immune cells. This barrier is maintained by a stable microbiome which helps to regulate epithelial energy metabolism, prevents pathogen colonization, and helps control immune tolerance. If the integrity of the barriers and microbial balance is compromised, the bacterial products can enter into circulation and lead to systemic inflammation. These alterations have been referred to as "dysbiosis," but this term should be used with caution, as there is no microbial profile that can be identified as health or disease.

The gut microflora relay messages to distant organs via neural, immune, endocrine and metabolic routes. The microbiota–gut–brain axis is not unidirectional in that the microbiota does not dictate brain function, but is yourself regulated by it, via vagal signalling, cytokines, microbial metabolites, neurotransmitter precursors and the hypothalamic–pituitary–adrenal activity (Cryan et al., 2019). There are some reports indicating changes in the pattern of microbes in anxiety and depression, although they are not consistent due to the variability of diets, medication exposure, geography, sequencing techniques and diagnostic criteria. Existing evidence suggests association, but not any specific microbial signature, or a single treatment for the microbiome that would be effective in all individuals (Simpson et al., 2021).

Another important axis of host–microbial communication is the gut–liver axis. Nutrient, microbial metabolic and bacterial products are constantly entering the liver through the portal blood. Dysbiosis, increased intestinal permeability, disturbed bile acid metabolism, endotoxin exposure, and disturbed production of microbial metabolites may all play a role in the inflammation of the liver in NAFLD, and in the deposition of lipid in the liver. The processes are interrelated with obesity, insulin resistance, dietary factors, and genetic predisposition and thus cannot be considered as disease causes per se (Hrncir et al., 2021).

Overall, the gut microbiome is a dynamic and integrated biological system that links diet, metabolism, immunity, intestinal barrier, brain and liver. It is not just a matter of the relative abundance of individual microorganisms, but also of the stability of the microbial communities, the metabolic potential of microbial communities, host properties and the context of the environment. A systems-level view is crucial for understanding the potential impact of Ayurvedic dietary and lifestyle practices, and therapeutic interventions, on gastrointestinal microecology and host well-being.

3. Ayurvedic Framework of Digestion, Metabolism and Intestinal Homeostasis

In Ayurveda, digestion, assimilation, nourishment of tissues, elimination and immunity are believed to rely on the proper functioning of Agni, thus making this the main key for gastrointestinal health. Ayurveda does not see digestion simply as

a mechanical process; it sees it as an orchestrated process, dependent upon the quality of the food, digestive strength, individual constitution, lifestyle, weather and mood. In modern microbiome research, a systems-oriented approach is gaining importance, as it has been demonstrated that the interaction of diet, microbial metabolism, host physiology, circadian rhythms and disease susceptibility influences intestinal function. Dysfunctions in these interactions have been linked to obesity, type 2 diabetes and other metabolic diseases (Fan & Pedersen, 2021).

Agni is the main concept of Ayurveda related to digestion and metabolism. It is generally divided into Jatharagni, Bhutagni and Dhatvagni. The primary digestive activity in the gastrointestinal tract is known as jatharagni and regulate the initial digestion and assimilation of food. One transformation, that of the elemental components of food into forms suitable for the body is called Bhutagni and the other, tissue-level metabolic processing that supports the formation and maintenance of the seven Dhatus, is called Dhatvagni. Agni can be balanced, irregular, intense and weak, known as Sama, Vishama, Tikshna and Manda Agni respectively. These functional states are not the same as the microbial signatures, but could serve as a platform to investigate differences in digestive efficiency, nutrient utilization, metabolic reactions and intestinal resilience. Figure 1 shows the proposed interrelationship between Ayurvedic food and lifestyle guidelines, Agni, dosha, Prakriti, gut balance and health. microbial systemic

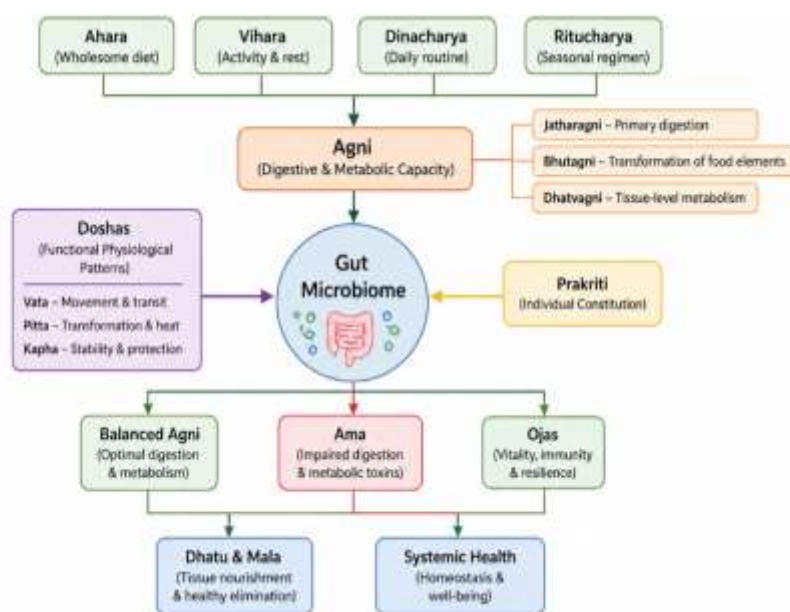


Figure 1.

Framework of Gut Microbiome Homeostasis

Ayurvedic

According to Ayurveda, when Agni is weak, the incomplete digestion and metabolism result in the formation of Amas which is a disease causing substance. Traditionally Ama is related to heaviness, tiredness, lack of appetite, irregular elimination, inflammation and blockage of the physiological channels. It should not be directly correlated with dysbiosis, endotoxemia or individual markers. It might still be used as a hypothesis-generating variable when studying whether a combination of dysfunction of digestion, changes in microbial metabolism, increased intestinal permeability and systemic inflammation exist in some people. It is important to study relationships like these, which are multi-dimensional, rather than to look for a universal cause of IBS by the microbes (Pittayanon et al., 2019).

The three doshas have different effects on the digestive physiology. Vata controls the movement, intestinal transit and elimination, Pitta is related to the transformation, heat and enzymatic activity, and Kapha provides lubrication, stability and protection of the mucosal surfaces. It is a well-known imbalance that is associated with bloating, acidity, constipation, diarrhoea, slow digestion or overeating. The 'Prakriti' or the constitutional pattern formed by the relative predominance of the Doshas is the basis for making personalised recommendations for diet and lifestyle. This focus on interindividual variation is consistent with the current research on microbial rhythms and metabolic responses, which show that microbial rhythms and metabolic response are not all alike and may predict the risk for type 2 diabetes (Reitmeier et al., 2020).

Ojas is energy, strength and the perfect digestion and nourishment of the tissues. It has no biomedical equivalent, but can be discussed in the context of immune competence, barrier integrity, metabolic stability and recovery capacity. These functions might be relevant to the potential of intestinal ecology to enhance outcomes of interest in overweight and obese adults, and exploratory findings suggest that supplementation with *Akkermansia muciniphila* may be beneficial for selected metabolic markers (Depommier et al., 2019).

According to Ayurveda, there are four ways to maintain the Agni; namely Ahara, Vihara, Dinacharya and Ritucharya. Ahara is all about the quality, compatibility, amount, timing and constitution of food. Activity, rest, sleep and emotional regulation are all part of Vihara; while Dinacharya and Ritucharya correlate behaviour with daily and seasonal cycles. Regularity and adaptation is emphasized, not uniformity. The importance of their relevance is supported by evidence of the effect of sustained diets, such as Mediterranean diets, on gut microbiome and health-related outcomes in older people (Cassidy, 2020). These ideas together offer a view of digestion as a personal ecological process and offer a framework for analyzing the potential effects that Ayurvedic practices could have on microbial function and metabolism, intestinal homeostasis, and health over time. Despite all of this, scientific translation must not sacrifice traditional constructs from Ayurveda to oversimplified or provisional biomedical counterparts in the process of interpretation and translation,

although it does necessitate the validation of Ayurvedic phenotyping, standardized interventions, longitudinal assessment of the microbiome and separation of conceptual analogy from mechanism.

4. Biological Interfaces Between Ayurvedic Constructs and Host–Microbiome Physiology

While there may be parallels and similarities between the physiology of the Ayurvedic constructs and the host–microbiome, direct equivalency is best explored through the lens of functional parallels. In Ayurveda, digestion, metabolism, nourishment of the tissues, immunity, and body communications are all interconnected, whereas in microbiome science, the effect of these is described as a result of interactions between microbial communities and tissues, diet, metabolites, and immune pathways. Both viewpoints agree that health of the gastrointestinal tract requires regulation, not just one organ or one factor. The ayurvedic concepts are thus considered as hypothesis generating frameworks and not an alternative to the microbial taxa, biomarkers, or molecular pathways.

Agni is the most clear as it is the power of digestion, transformation and metabolism. These functions can be explored in the context of microbes and the microbiome in terms of nutrient breakdown, microbial fermentation, metabolite production, epithelial energy supply and host metabolic response. Conceptually, Balanced Agni could be linked to the efficient digestion and stable metabolic adaptation, and disturbed Agni can be related to variable transit, incomplete digestion of nutrients and changed activity of the microbes. To interpret the relationship with the microbiome profiles, validated assessment methods for these associations are needed, which means that the development and psychometric evaluation of Agni instruments are essential (Roy et al., 2026).

Traditionally Ama is considered to be a poisonous byproduct of incomplete digestion and disturbed metabolism. It should not be directly associated with dysbiosis, endotoxemia or inflammation, but can be tested in these biological contexts. Microbial imbalance can impact fermentation, bile acid metabolism, permeability of the gut and immune activation and have systemic effects beyond the gut. Current evidence indicates a link between alteration of microbial composition and their functionality with many disorders, but no microbial pattern of change is associated with disease across populations (Gomaa, 2020). Ama can therefore be considered to be a multi-dimensional phenomenon, including impaired digestion, disturbed microbial metabolism, barrier dysfunction and inflammatory signalling.

Inter individual variation is an introduction by dosha and prakriti. It has been traditionally associated with the differences in appetite, bowel pattern, metabolic intensity, body structure and physiological responsiveness, all three characteristics of Vata, Pitta and Kapha. These characteristics could have a direct effect on food choice, transit time, bile exposure, mucus production and other ecological factors that could affect the microbial community. Variation in the context of the microbial diversity, metabolic pathways and dietary response could then be explored based on Prakriti. There are, however, significant changes in the composition of a healthy microbiome as a function of age, geography, environment, lifestyle, and disease that make comparisons across individuals inappropriate (Rinninella et al., 2019).

Ojas is the result of good digestion and nourishment of the tissues and is a framework for vitality, resistance and immune stability. These areas of potential biological interface may be mucosal immunity, epithelial integrity, resistance to pathogen colonization, and production of beneficial microbial metabolites. As the diversity and function of microbes change with age, these changes can impair these protective mechanisms and lead to frailty, inflammation, and decreased resilience (Ghosh et al., 2022). Therefore, Ojas could be examined by combining multiple markers of immunity, barrier function, metabolic health and Ojas recovery, instead of a single one.

Srotas is used for an interpretation at a system level level, which describes channels through which nutrients, wastes and regulatory signals travel. Some prudent contemporary analogies might be: intestinal barrier communication, portal circulation, immune networks, endocrine systems and microbial metabolite signalling. Intestinal ecology and distant organs, as shown by the presence of short-chain fatty acids, secondary bile acids, indole derivatives and other microbial products, provide examples of how the local microbial environment can impact systemic physiology.

Diet is a kind of mediator, linking these interfaces. Microbial substrates and metabolite patterns, immune response and host metabolism may change with food quality, timing, composition and compatibility. The results from the NU-AGE intervention suggest that the ability to alter the gut microbiome through a sustained Mediterranean-type dietary pattern has the potential to support positive outcomes for frailty-related health outcomes in older adults (Cassidy, 2020). This facilitates the study of dietary personalization as a strategy of Ayurveda, and highlights that results are dependent upon the age, baseline microbiota, host phenotype and adherence of the individual.

Overall, the most salient points of intersection between Ayurvedic constructs and microbiome physiology are in terms of function, regulation, and individual variability. Based on the above, testable questions can be raised about digestion, microbial metabolism, barrier integrity, immune regulation, and systemic communication, using the aid of Agni, Ama, Dosha, Prakriti, Ojas and Srotas. Their scientific value is the structured interdisciplinary interpretation with the correct concept, if the concept is not confused with the biological identity and in the future, the studies will be based on the same Ayurvedic evaluations, longitudinal microbiome analysis, metabolomics and clinically relevant outcomes.

5. Ayurvedic Diet and Lifestyle as Modulators of the Gut Microbiome

Ayurvedic Diet and Lifestyle guidelines offer an individual plan to maintain digestive balance, metabolic flexibility and intestinal homeostasis. Instead of a one-size-fits-all approach, Ayurveda takes into account various factors such as Prakriti (body type), digestive strength, age, season, activity and susceptibility to disease while choosing food and daily routines. This personalised orientation is very similar to the growing awareness of the role host genetics, microbial composition, host metabolism and environmental exposure all play in their dietary response. To close this gap, the possibility of

introducing a new concept of Prakriti-based stratification has been proposed, which is still preliminary but needs to be validated in larger and more diverse populations (Jnana et al., 2020).

Ayurveda considers the action of foods as Rasa, Guna, Virya and Vipaka. The taste is Rasa, qualities like heaviness, lightness, dryness or unctuousness is Guna, heating or cooling potency is Virya and post digestive potency is Vipaka. These categories are not to be interpreted as strictly synonymous with nutrients, metabolites or microbial pathways. They are useful to test hypotheses regarding the effects of foods on appetite, satiety, secretion, motility, thermogenesis, fermentation and metabolism after a meal.

The idea of Viruddha Ahara is based on foods, food combinations, how they are prepared, when they are eaten or when they are not eaten, that are thought to be physiologically incompatible. Such practices can be explored from a more contemporary point of view for their impact on digestive efficiency, bile acid metabolism, microbial fermentation, intestinal permeability and inflammatory signalling. But these connections need to be proven through experiments, as the response of the microbiome depends on the host physiology, native microbial ecology, disease condition, and food environment (Hou et al., 2022).

Fermentable carbohydrates and phytochemicals from dietary fibre, whole grains, legumes, fruits, vegetables, nuts and seeds are crucial to maintaining a diverse metabolic environment and a diverse microbial community. They produce short-chain fatty acids, such as acetate, propionate and butyrate, during their fermentation. The metabolites have various functions, including the provision of energy to colonocytes and the secretion of mucus, maintenance of tight junctions, regulation of the immune system, and anti-inflammatory signalling, but these functions depend on the concentration, location of biosynthesis, and host status (Parada Venegas et al., 2019). Traditional fermented food products can also provide live microorganisms, organic acids and bioactive compounds, which can have varying benefits depending on the preparation, storage conditions, microbial composition and consumption. Table 2 summarizes the potential Ayurvedic constructs that can be related to host–microbiome physiology.

Table 2. Ayurvedic Constructs and Their Potential Microbiome Interfaces

Ayurvedic construct	Functional meaning	Potential microbiome interface
Agni	Digestive and metabolic capacity	Nutrient digestion, fermentation and metabolite production
Ama	Impaired digestion and metabolic disturbance	Dysbiosis, barrier dysfunction and inflammation
Dosha	Functional physiological patterns	Variations in motility, secretion and metabolism
Prakriti	Individual constitutional phenotype	Differences in microbial composition and dietary response
Ojas	Vitality, immunity and resilience	Mucosal immunity and intestinal barrier integrity
Srotas	Systemic transport and communication pathways	Microbial metabolite and inter-organ signalling
Ahara	Diet quality, timing and compatibility	Microbial substrate availability and ecological stability

The polyphenols, essential oils, alkaloids and other bioactive constituents in ayurvedic herbs and spices can have effects on microbial growth or get transformed by microbes into constituents with different activity. Turmeric, ginger, cumin, coriander, fennel and black pepper can therefore have a metabolic and inflammatory effect on the intestinal flora. It is important to note, however, that the dosage, formulation, bioavailability and safety of culinary use are very different from concentrated supplementation.

The eating schedule, regularity of digestion and moderation play a pivotal role in Ayurvedic principles. Regular meals, avoiding repeated over-feeding and sufficient mealtimes could facilitate the normal functioning of the motor system, the circadian system, and the microbial rhythm. Ritucharya is an extension of this where diet and behaviour is modified according to the change of climatic conditions, appetite, activity and physiological need of the season. The purpose of fasting and conscious eating is to decrease digestive load and have an increased awareness of hunger and satiety, but this depends on the length of this fasting, the nutrients consumed in this period, health status and the composition of the meals that follow.

Vihara enhances the bliss of Ahara not just through sleep, but also through physical activity, yoga, stress management and routine. This can affect the transit of the intestines, autonomic balance, neuroendocrine signalling, immunity, and microbial stability. Association of Prakriti classification and KCNJ11 variation in type 2 diabetes shows the importance of the integration of Ayurvedic phenotyping with molecular markers, but it does not provide the direct evidence for the mechanism of action of microbiome.

This holistic view acknowledges that positive effects will not be seen from one single factor such as food quality, but rather through the ongoing interplay of behaviour, regularity, constitutional factors, and function of the microbes.

The overall effect of the diet and lifestyle recommendations of the Ayurvedic system on the gut microbiome could be through multiple mechanisms including alterations in substrate availability, circadian regulation, stress physiology, motility, barrier function and host metabolism. If they are scientific value, it is not of the individual food or practice, but of the coordinated food and practice pattern, that is Ahara and Vihara. Further studies are warranted using standardized Prakriti assessment, definite interventions, dietary monitoring, longitudinally collected microbiomes, metabolomics and

clinically relevant outcomes to see if the personalized Ayurvedic regimen could have an impact on enhancing the microbial resilience and human health.

6. Microbiome-Modulating Potential of Ayurvedic Therapeutics

The gut microbiome can be affected by Ayurvedic therapeutics by complex interactions between medicinal plants, polyherbal formulations, dietary carriers, microbial biotransformation, immune regulation and intestinal barrier function. Polyphenols, alkaloids, terpenoids and other bioactive components present in individual herbs like turmeric, ginger, amla, guduchi, licorice and ashwagandha could influence the growth, fermentation and production of metabolites of microbes. Their biological effects are not likely to be the result of a single compound because a number of phytochemicals are poorly absorbed in the intestine and are then metabolized by the gut flora. The microbiome could thus influence the bioavailability and activity of the compounds of herbs, and herbs could influence the metabolic pathways and microbial community. Multiple ingredients may work in complementary, additive and/or synergistic ways with each other, adding to the complexity of polyherbal formulations. These effects could include changes in microbial diversity, the production of short-chain fatty acids, bile acid metabolism, epithelial barrier, and inflammatory signalling. This complexity also makes it difficult to identify which are active constituents and to replicate therapeutic effects. Validation of the evaluation needs to be carried out on authenticated plant materials, well-defined preparative and extraction procedures, standardized doses, chemical characterization and comparison of whole formulations and their individual components.

Fibres, resistant starches, oligosaccharides and polyphenols are present in several Ayurvedic preparations which have potential as prebiotics as they are able to act as substrates for beneficial microorganisms. Traditional fermented preparations can also include live microbe or products of fermentation. However, they can't simply be termed as probiotics and postbiotics. A probiotic appears to be a preparation of identified live bacteria or yeasts that have been shown to have health benefits to humans or animals; a postbiotic is a defined preparation of inanimate micro-organisms or components thereof that have proven biological activity. The differences are significant as probiotics, prebiotics, and postbiotics act on the microbial ecology, mucosal immunity, and intestinal homeostasis in various ways (Liu et al., 2022).

Microbial biotransformation is a very important aspect of Ayurvedic pharmacology. Gut bacteria can break down glycosides, break down or deconjugate complex molecules, and alter the absorption and biological activity of plant derived compounds. Herbal constituents, in turn, could influence the production of short-chain fatty acids and the metabolism of tryptophan, as well as the composition of bile acids and the microbial signalling. Ghee is widely used in Ayurveda as a dietary and medicinal carrier as the lipid matrix could be ideal for transporting fat soluble components. Its benefits suggested to be related to microbiome, however, have not been directly proven in clinical settings but rather extrapolating from the traditional use or the general nutritional properties of the plant (Kataria & Singh, 2024).

Rasayana therapies are basically used to increase vitality, recovery and resistance to illness. As for their potential relevance from a microbiome point of view, they may play a role in supporting ecological resilience, metabolic stability, mucosal immunity and barrier integrity. The effects of these factors will probably be dependent on both the formulation itself and the diet, sleep, stress and physical activity of the animals. Changes in the diversity of microbes and metabolites following exercise highlight the interaction between lifestyle factors and therapeutics, and how these affect host–microbiome physiology (Mailing et al., 2019).

However, the cleansing practices of panchakarma and similar practices need special care regarding their interpretation. The alterations seen in the microbiome following any such treatment may be due to the dietary restriction, bowel evacuation, herbal drugs, fasting, hydration or the change in daily routine and not any one cleansing process. The effects of these components should thus be differentiated in controlled studies and examined for short- and long-term recovery of the microorganisms as well as gastrointestinal symptoms, hydration, electrolyte balance and adverse events.

Microbial metabolites, epithelial signalling and immune activity are also potential targets for ayurvedic therapies that can impact inflammation and intestinal permeability. However, multi-omics analysis of inflammatory bowel disease reveals that perturbations of the microbiome are highly individual, and that shifts in microbes, metabolites, host pathways and environmental exposures occur together in concert (Lloyd-Price et al., 2019). All of this makes it difficult to maintain an optimistic outlook that one herb or formulation can be used to re-establish a “healthy” microbiome.

Another critical safety issue is herb–drug–microbiome interactions, which involve the potential for herb–drug interactions, potential alteration of drug–metabolizing enzymes, drug transporters, microbial metabolism, and the possible effect on drug absorption. Botanical substitution, batch variability, contamination, heavy metals, microbial load and adulteration should be taken into consideration for quality control. In summary, Ayurvedic therapeutics show potential for plausibility in modulation of microbiome, but require standardisation of the formulations, mechanistic studies, controlled trials, longitudinal microbiome studies, metabolomics, and clinically relevant safety and efficacy measures.

7. Clinical and Translational Applications of Ayurveda–Microbiome Integration

Clinical application of Ayurveda and microbiome sciences is a promising approach to create personalized strategies for gastrointestinal, metabolic, immune, neuropsychological and age-related conditions. The translative value of it does not lie in the identification of specific microorganisms to Ayurvedic concepts, but in exploring whether interventions based on Prakriti, Agni, Ahara and Vihara can result in reproducible changes in microbial function, host metabolism, intestinal barrier integrity and patient-centred outcomes. Currently, this is an emerging field and the majority of applications suggested should be regarded as "hypothesis" based and not as clinical practice.

A logical starting point is the functional gastrointestinal disorders, such as irritable bowel syndrome (IBS), constipation, diarrhoea, bloating and irregular bowel habits. These conditions are caused by multi-factors including intestinal motility, visceral sensitivity, food ingestion, stress, immune signaling and microbial metabolism. Word of mouth, a dietary regimen tailored specifically to the individual, and the use of digestive-enhancing herbs and behavioral modifications are also used often in Ayurvedic treatment. These multimodal therapies can have an impact on the gut, stress responses, stool consistency, abdominal symptoms, and transit. However, there are a number of trials that need to be well-designed to differentiate microbiome mediated effects from effects of dietary exclusion, symptom expectation, routine changes or therapeutic support in a non-specific manner. The potential clinical domains and the related Ayurveda – Microbiome intervention strategies are mentioned in Table 3.

Table 3. Potential Clinical Domains for Ayurveda–Microbiome–Based Interventions

Clinical domain	Ayurvedic strategy	Microbiome-related focus	Potential application
Gastrointestinal disorders	Personalized diet, herbs and meal regulation	Motility, fermentation and barrier integrity	Symptom and bowel-function support
Inflammatory bowel disease	Anti-inflammatory and dietary adjuncts	Mucosal immunity and epithelial integrity	Adjunctive symptom management
Metabolic disorders	Prakriti-based diet and lifestyle	SCFAs, insulin sensitivity and bile acids	Metabolic and liver-health support
Neuropsychological health	Yoga, sleep regulation and herbs	Gut–brain and neuroimmune signalling	Stress, mood and sleep support
Healthy ageing	Dinacharya, Ritucharya and moderate diet	Microbial resilience and immunity	Frailty prevention and healthy ageing
Precision care	Prakriti and Agni assessment	Microbiome function and host phenotype	Personalized intervention design

The inflammatory bowel disease (IBD) context is more complex to translate, with genetic susceptibility, epithelial dysfunction, immune dysregulation, environmental exposures, and changes in the microbial ecology all involved in the pathogenesis of the disease. Anti-inflammatory or barrier supporting ayurvedic formulations might be considered as add-on treatment but not as replacement for proven medical treatment. The same care is needed when foods are added to care in the form of fermentation. They differ in their microbial and metabolic composition, and cannot be classified as probiotics without the presence of certain strains and its clinical effects have been proven (Marco et al., 2021).

Other areas of interest include obesity, metabolic syndrome, type 2 diabetes, and non-alcoholic fatty liver disease which are all linked to changes in microbial metabolism, low-grade inflammation, insulin sensitivity, disruption in bile acid and barrier function. Personalisation of nutrition on the basis of Prakriti may be useful to explain some of the differences in appetite, food tolerance, metabolic phenotype and medication response. However, microbiome-based recommendations should be on validated patterns of function not abundance of individual taxa. The benefits of probiotics interventions can impact on the production of SCFAs, nutrition of the epithelium, immune system regulation, and metabolic signalling, and depend on the type of probiotic, dosage, diet, pre-existing microbiota and host factors (Markowiak-Kopeć & Śliżewska, 2020).

Another area of relevance in which the gut–brain axis could be investigated is in the area of nutrition. Microbial metabolites can alter neuroimmune and neuroendocrine pathways and stress and anxiety and depression have the potential to alter motility, permeability, immune tone and microbial composition. There are population level studies that have correlated microbial neuroactive potential to quality of life and depression, but this has not been demonstrated to be causal (Valles-Colomer et al., 2019). Some Ayurvedic methods such as yoga, meditation, sleep management, nutrition and certain herbs can influence the psychological and the gastrointestinal pathways. However, the microbiota–gut–brain axis is a two-way street, and complex psychiatric disorders cannot be found to be a single microbial pattern or solved by a single intervention focused on the microbiome (Morais et al., 2021).

There is also a relevant domain of healthy ageing, of translation. Frailty and chronic inflammation can be caused by changes in diet, immunity, mobility, and exposure to medications and microbes as a result of their age. The importance of daily routine, seasonal changes, moderate eating, exercise, and rest that are highlighted in Ayurvedic medicine could serve as a framework for microbiome-enhancing longevity programs. These treatments should be evaluated using multiple parameters such as mobility, nutrition, markers of inflammation, and gastrointestinal function/intestinal stability.

Future clinical translation will need to incorporate metagenomics and metabolomics, dietary assessment, standardized ayurvedic classification along with clinical phenotyping. Commercial microbiome tests have not yet been validated sufficiently for routine treatment to individual patients, however in the future, they might be able to help guide dietary, herbal, fermented food or lifestyle recommendations for specific patient populations. The most plausible approach is then a conservative precision-health approach where Ayurvedic personalization provides support in designing the intervention, and microbial science is used to assess mechanism, safety, efficacy and reproducibility. Well-designed studies should contain the proper controls, sufficient sample size, long term follow-up studies, standard formulations, adverse event monitoring and clinically meaningful endpoints to allow for microbial changes to be interpreted along with symptom improvement, metabolic response, quality of life, and the use of conventional treatment.

8. CONCLUSION

The future of Ayurveda-microbiome studies will not be a question of finding an exact match between microbe-intervention and an Ayurveda concept, but rather a question of creating strong frameworks that can be used to evaluate relationships

between digestion, metabolism, immunity, behaviour and ecological resilience. The idea of Agni, Prakriti, Ama, Ojas and Srotas might be helpful as clinical phenotypes that lead to measurable hypotheses rather than as molecular mechanisms. This separation helps to maintain the purity of the Ayurvedic theory but also helps assess the biological plausibility of the theory in the light of modern microbiology. A meaningful translational model should incorporate standardized assessment of Ayurvedic medicine, dietary history, metagenomics, metabolomics, inflammatory markers, barrier-function measurements and outcomes measured in the patient. This integration could be of great importance in explaining why some people feel better after eating a particular food, drinking a certain herb or following a specific lifestyle or dietary regimen, and may facilitate going beyond a one-size-fits-all approach to using microbiome research to guide care. There is great potential for success with combinations of food quality, meal timing, sleep, physical activity, and techniques for managing stress, and then carefully tailored combinations of microbial targets, which would be multimodal interventions, rather than with any single microbial target. As the enthusiasm is accompanied by methodological discipline. Microbial changes should not be viewed as evidence of a therapeutic success without concurrent sustained clinical improvement, safety and reproducibility. Systems language of individuality and adaptation, and tools for validation and mechanism, can be brought by Ayurveda and microbiome science, respectively. Their fruitful interaction is thus not a so-called "proof" of anticipated convergence, but a development of a scientifically responsible model of personalized, preventive and integrative health throughout the lifespan.

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