

**TIMES
EVOKE**

THE MARVELS OF MICROBES

Did you know, humans compose just 0.01% of the total biomass on Earth while microbes — minute life forms including bacteria, algae, fungi, archaea, protozoa and viruses — compose over 17% of life on our planet? The evolution of microbes, found everywhere, from air to water, foliage to ground to a jar's lid and the skin on your hand, is traced back to 3.7 billion years. Microbes are literally the building blocks of life for they produce oxygen, impact water and sequester carbon dioxide. Microbes recycle life itself, decomposing nutrients, so new living organisms can access these.

Yet, despite being vital ecosystem engineers, microbes are often blamed for causing diseases. However, while there are over one trillion microbial species on Earth, only 1,400 can cause illnesses to humans. The rest are benign or beneficial — microbes in fact compose much of the human body, guarding our immune and nervous systems, producing vitamins and detoxifying chemicals. With every individual hosting 10 microorganisms for each human cell, scientists term this universe within us the 'microbiome'. The World Economic Forum reports that globally, peoples' responses to Covid-19 were influenced by their gut microbiome, patients in Japan recovering much better due to abundant *Collinsella* bacteria which blocks the coronavirus from binding to cells, reducing its persistence. Little wonder the World Bank is strengthening clinical research into using microbes to stem epidemics. Microbes reflect how the well-being of Earth and humans are interlinked — as we damage one, the other suffers too. Currently, habitat destruction is altering microbial life, changing Earth's geophysical processes. Meanwhile, as humans adopt unhealthy lifestyles, their microbial ecosystem is damaged, causing burgeoning diseases.

As Times Evoke's global experts emphasise, understanding microbes is fundamental to maintaining healthy environments inside and around us. The discovery of microbes in the 13th century was a breakthrough for humanity, changing how we view the world, not as an inexplicable series of mysteries, but a scientifically intertwined tapestry of life, where the most minute beings enable the mightiest to live. A new understanding of microbial life can rejuvenate our respect for nature's laws. Join Times Evoke in exploring microbes, which empower the life you lead.

'Microbes cause Earth to function — from plants to humans, we all live due to microbial activity'

Roberto Kolter is professor emeritus of microbiology at Harvard University. Speaking to Srijana Mitra Das at Times Evoke, he discusses why microbes are essential to life, their brilliance — and their beauty:

What is the core of your research?

I've researched the world of bacteria for 35 years before I retired. We began with a very molecular approach, studying how bacteria react upon experiencing different types of stresses. That took us to studying behaviours in assemblages of microbes living on surfaces. Over the years, from a molecular approach, my interest grew to questions like how bacteria interact with algae in the oceans to generate a large part of Earth's sulphur cycle, impact cloud formation, the climate, etc.



Why are microbes essential to Earth's species?

Microbial activities are foundational for the functioning of our planet — without microbes, there is no chance that plants and animals, which includes us humans, would have ever evolved or been able to sustain life. The activities of microbes make the conditions of this planet propitious for life. Microbes are involved in each one of Earth's large geochemical cycles — they are the producers of oxygen in the oceans. They generate much of the sulphur and nitrogen which living beings need. In plants, chloroplast, the remnants of a bacteria, conducts photosynthesis to produce energy and oxygen. Microbial activity in soil causes food to grow. Every major activity on Earth involves microbes.

Photo Courtesy: R. Kolter & S. Chimileski



GLOWING ALL AROUND YOU: Colonies of different kinds of bacteria and fungi, some producing essential antibiotics, as seen here on agar plates, often display a shimmering, jewelled appearance



THE WORLD WITHIN ONE DROP: In their book 'Life At The Edge of Sight', microbiologists Roberto Kolter and Scott Chimileski show microbial worlds existing inside entities like a drop of water as intricate universes which are multidimensional and incredibly beautiful

Why do you say every human being is an ecosystem with microbes?

An ecosystem means any place where multiple species interact with each other. We think of ourselves as the human body but in fact, we are surrounded by a microbial cloud. Our skin is more than epidermal cells — these interact constantly with microbial organisms living on the surface. Inside us, our gut tract is loaded with thousands of bacterial species, without which we would not have good health.

Most people think of microbes as bacteria which cause illnesses — how accurate is that?

That's terribly inaccurate. There are millions of species of microbes on our planet, of which just a few can cause disease in humans. This is an extremely small minority. But there are innumerable diverse species which are very beneficial to us. Think of food — to make plant growth possible, you need a certain amount of nitrogen. But the nitrogen in the atmosphere can't be used by plants for growth. That must be made accessible or fixed into ammonia, urea or some compound plants can use — only microbes can do that. Think of every plant we consume and then, the animals that eat plants — each one is dependent on microbial activity. Much of the food we consume is also

processed by microbes — in cooking, microbes transform food, making it safer. That was recognised over 10,000 years ago when humans used microbes through fermentation, making sanitised beverages, creating bread, yogurt, cheese and so on.

THE SMALL BANG THEORY

What's been among your most surprising discoveries about microbes?

One of the most remarkable findings we made relates to the speed of evolution in the microbial world — given the right conditions, you can literally see one species overtaking another in hours. We normally think of evolution as a slow process but the tempo of evolution in the microbial world is mind-boggling. Think of how quickly, for instance, an antibiotic-resistant bacterium can act on a patient — that is the evolutionary process happening right there.

Is climate change impacting microbes now?

Yes. There is direct evidence already that microbial life is changing dramatically due to climate change. This is seen in the oceans and soil and through wildfires, generated by extreme weather events. We have also dangerously disturbed microbial life through the use of fertilisers over the last seven decades — microbial activities in soil worldwide have changed enormously as a result. Depleted soils won't be able to stay

productive in the long run — that will cause problems in food production. So, as communities worldwide struggle to deal with the challenges of climate change, they will also face greater soil erosion and decreased food production.

How can we help to preserve microbes?

One of the wonderful things about microbes is if, in general, you let an ecosystem be, they re-establish themselves in a really short time. We simply need to leave ecosystems alone. There is far too much anthropogenic interference — just being respectful of the planet is a key step.

Why do you emphasise microbial beauty?

When you show a person the beauty that abounds within the world of microbes, it sparks great curiosity in their mind. For example, just walk in a forest and observe lichen, dazzling conglomerates of microbes.

What is the significance of 'geosmine'?

This is a wonderful molecule produced by bacteria and fungi in the soil which we



WAIT AND WATCH: We often walk past microbe-rich communities, from ponds to puddles, trees to domestic surfaces. But it is here that many of the explanations of our own life and evolution are to be found

humans like. Insects recognise this molecule and coat themselves with these organisms — this provides the microorganisms a way to transport themselves to greener pastures. These microorganisms make molecules we call antibiotics that balance ecosystems and keep pathogens away — humans possibly like geosmine, found literally in a handful of moist soil, because we recognise these molecules are so beneficial to our health. Geosmine itself is the smell of earth, 'smine' being smell and 'geo' earth.

MACRO SKILLS

Microscopic plankton in the ocean convert carbon dioxide (CO₂) and water (H₂O) into carbohydrates and oxygen (O₂) — they produce over half the oxygen we breathe. Microbes thrive everywhere — a single grain of sand can house 1,00,000 bacteria

Clouds abound with bacteria that grab water vapour in the atmosphere to make cloud droplets. But these droplets and crystals need a solid or liquid surface to collect on — bacteria provide that surface, becoming 'cloud condensation nuclei', determining our weather

The seas are alive with microbes — 90% of the weight of marine beings is from microbes. These produce nitrogen and oxygen in the deepest depths where no sunlight pervades. Microbes even create 'the scent of the sea', with bacteria breaking down chemical compounds, releasing aromatic dimethyl sulfide, the sea's smell

About 10% of the natural milk a baby drinks contains sugars it can't digest — these sugars nourish microbes in the baby's gut which strengthen it and reduce inflammation, creating an ecosystem of good health in infants

Research: Encyclopaedia Britannica, National Geographic, LiveScience, Nature, Smithsonian Magazine

FRIENDLY DEALS

Microbes and other living beings famously help each other via 'mutualism' or symbiosis — aphids or sap-sucking insects house the *Buchnera aphidicola* bacterium within them which, in exchange for a home, help aphids acquire amino acids and combat predator wasps. The famously hard-working leaf cutter ant also needs a helping hand — it houses a fungus in its system that helps it digest its laborious harvests of freshly cut leaves

In shallow, sunlit waters, corals live a symbiotic life with one-celled algae called zooxanthellae. This resides inside the coral polyp and performs photosynthesis, converting power from the sun and carbon dioxide into organic and chemical energy. This produces the oxygen and other nutrients the coral needs to survive, while the polyp provides zooxanthellae with carbon dioxide, nutrients — and a glowingly vibrant home

Bacteria can consume the keratin of bird feathers, leaving birds unable to fly — but hoopes stall these harmful bacteria by cultivating friendly symbiotic bacteria in special glands. These bacterial aids exude antiseptics called bacteriocins that destroy the keratin-consuming bacteria. However, hoopes apply just enough antiseptic to slow down keratin degradation, staving off acquiring a weakening resistance — and proving nature's infinite wisdom again

'Microbes are so resilient, they can help us adapt to climate change'

Steven D. Allison teaches microbial and ecosystem ecology at the University of California, Irvine. He tells Times Evoke about how microbes can benefit us in a warming world:

I'm interested in studying how microorganisms like bacteria and fungi are responding to climate change as well as how they could help us address the climate problem through the important functions they provide. Microbes are everywhere in our environment, and vital for our planetary cycles as they provide the opposite function to plants — the latter take carbon dioxide out of the atmosphere during photosynthesis while taking up nutrients from the soil and storing these in their biomass. When plants, animals or plankton perish, microbes recycle all these nutrient and carbon forms, making them available for new life to grow. Microbes also do carbon sequestration — perished microbes stick in the soil, adding reformulated compounds to earth. This strengthens soil health.



STAYING ALIVE: Studies of climate change impacts on soil microbes were conducted recently at the Loma Ridge Global Change Experiment in Irvine, California, where plastic covers reduced rainfall in order to reach experimental drought plots by nearly 50%. Interestingly, the microbial communities managed to survive the climate shock

most practical ways to add these to certain soils, like degraded ones, to boost crop growth.

Microbe resilience is fascinating. These are incredibly

SALT OF THE EARTH

complex organisms and almost four billion years of evolutionary history have shaped the microbes present in the planet today. Microbes also evolve very quickly in response to changes in climate — they can alter their genetic material almost in real time. Different species can take on new roles too — hopefully that will offer us some buffering against climate shocks. If a certain microbe helps plants grow, but perishes in a heatwave, another heat-adapted type could take over and provide a similar benefit. That replacement and buffering capacity is evident across the hugely diverse microbiomes we see around the world.

We recently conducted a study on this — we took microbes living on the top of the mountains in southern California and another type living in the hot deserts. We switched them, putting the mountain microbes in the desert and vice versa. We're talking of a five to ten-degree change in temperature but I was

shocked to see the microbe sets did just fine — they could cope with that massive temperature shift and continue their functions, breaking down and recycling perished material. There is huge metabolic and genetic potential in microbes that adapts fast to climate change.

Other research also shows microbes have very interesting ways to cope with the environment. Within just a few generations, we can see major genetic changes which help them adapt. Microbes have many 'life history strategies' or diverse ways to deal with stress, acquire resources, obtain chemical compounds, compete and interact with each other. Their complex networks of interactions determine Earth's geochemical cycles — they are incredibly resilient and yet, quite unappreciated.

'Microbes within us shape our immune system — saving our gut health is key'

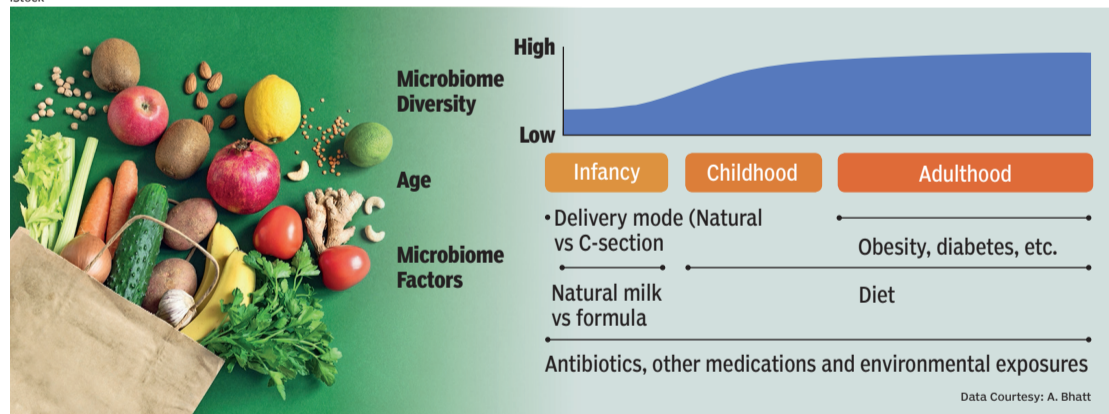
Ami Bhatt is professor of medicine and genetics at Stanford University. Speaking to Times Evoke, she discusses major scientific discoveries of how microbes impact our core well-being:

I am a physician scientist and my work focuses on how the microbiome and particularly the gut microbiome — the bacteria, viruses, fungi, etc., that live inside us — impact our health. I lead a research laboratory that studies these bacteria, etc., within our body. The greatest number live in the largest portion of our colon, the lower part of our digestive system — there are possibly trillions of microorganisms in our gut at any given time.

For a while, it was thought these microorganisms were just passengers, taking a ride through us to other directions. But intricate research has since shown that animals born without a microbiome in what we term 'germ-free conditions' suffer from very altered biology, lack having ineffective immune systems. So, the microbes living within us are not present there by happenstance — they are actually critical to shaping our immune system and biology.

Interestingly, the human gut microbiome is unique in every being — it's like our fingerprint. Even identical twins have different microbiomes. Our studies have shown that people who live together sometimes share some strains but there are thousands of microbes in an individual and you may share just one or two strains with people living with you.

Our choices can powerfully affect this extraordinary entity. Food is critical since what we eat is what our microbiome gets exposed to. Currently, evidence shows that countries where people used to traditionally eat more vegetables



YOU ARE WHAT YOU EAT: A healthy diet shapes our gut resilience which can influence disorders ranging from diabetes to obesity, autism, Parkinson's, Alzheimer's, schizophrenia and malaises impacted by what scientists call the 'gut-brain axis'

and wholegrains and are now turning to processed foods have higher rates of obesity-related disorders and metabolic diseases like diabetes — I'd be fascinated to study changes in the gut microbiome as well.

Another key area my lab works on is understanding how the microbiome impacts people with cancers. We've been studying individuals who undergo transplants, researching why some people respond to therapies like immunotherapy while others do not, and whether the gut microbiome predisposes people to improved cancer-related outcomes. In patients who undergo blood, marrow and cell transplantation, a subset develops infection — our lab has shown that the gut microbiome can be a reservoir of pathogens that make it into the blood stream, causing infections. So, we're working on how to remodel the gut microbiome, so those pathogens are not present. The gut microbiome can also

impact vaccine responsiveness. Vaccines are essential to protect people from Covid-19, polio, hepatitis, etc. Since people's microbiomes are significantly impacted by their environment, lifestyles and diets, studies exploring the role of our microbiome in vaccine responsiveness could help us give a particular kind of person not just a vaccine but perhaps also a pill with various fibers to encourage the growth of certain bacteria, leading to better vaccine responsiveness.

Recently, we've been conducting research in Africa where we found the gut microbiome of people in rural versus urban areas to be quite different alongside being very different from people in high-income countries like the US. Given the health implications, it's critical to study the microbiomes of individuals across the world. In our field sites in South Africa, which were only five hours away from each other by car, human micro-

biomes were very different. However, we found that in rural areas, with increased access to processed foods and reduced access to fresh fruit and vegetables, people's microbiomes were gradually resembling those of urban residents.

Our gut microbiome is critical for health. To protect this, we must eat a diverse array of fresh foods as our bacteria are extremely dependent on the different fibers in our diet. Also, avoiding unnecessary antibiotics is important. In India, many antibiotics are easily available and when people are feeling a little ill, this can be quite tempting. But, for the most part, when a person has a viral infection, antibiotics won't have any benefits — but they actually harm our microbiome for the future. Further research by my lab and other scientists will illuminate how we can make far more informed choices to preserve a healthy microbial environment within our bodies, thereby maintaining our core well-being.

READERS WRITE

Dear Times Evoke, Every week, our entire family waits to read about the splendid world of nature in TE! The article on fragrances featuring Elise Vernon Pearlstine (4th June) was a revelation. We hope these wonderful articles evoke love for the environment among all humans. —Dr Ashima Mehta, Jodhpur

I was overwhelmed reading TE on plant fragrances. While reading it, I felt these all around myself. Nature is the most calming force and its perfumes, like rain on earth, give bliss. We must preserve nature for knowing joy itself. —Pooja Vaid, Kolkata

I love beautiful Times Evoke. This time, it uniquely explained how plants express their needs through aromas. TE's gorgeous articles are so relevant in the 21st century. —Jini Kennedy, Thiruvananthapuram

I'm always so surprised by the facts shared in Times Evoke by great writers and scientists. I'm interested in the environment and I'm very grateful to TE for giving us the aesthetic Evoke. Every fact it presents is so thoughtful. It keeps me awaiting more! —Rohan Baxi, 6th grade, Bhubaneswar

TE's interview with Elise Pearlstine was so aromatic! I've always been a nature lover but I never knew what I enjoyed doing is actually termed 'forest bathing'. I was amazed to know that plants emit fragrances for both attraction and protection. TE makes me look forward to the weekend! —Nivedita Rana, student, Ludhiana

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