Innovation
Frontline

Artificial
Intelligence

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Editorial

The contemporary global nutrition landscape presents a great opportunity for transformation. While modern agricultural practices have succeeded in producing abundant food, but persistent global challenges like undernutrition, obesity, and micronutrient deficiencies, reveal that production alone is insufficient. However, this very recognition opens new possibilities. By understanding challenges regarding how we grow, distribute, and consume food, we can reimagine food systems that prioritize nutrition and equity along with productivity.

The transformation of Indian agriculture over the past six decade exhibits revealing patterns. Policy interventions prioritizing wheat and rice production through targeted procurement, input subsidies, and irrigation infrastructure brought food sufficiency and created powerful economic incentives for crop pattern shifts. However, between 1965 and 2010, millet cultivation area declined by approximately 50 percent. Green revolution resulted in massive food grain production but remained concentrated around rice and wheat, leading to a monotonous cereal-based diet and the marginalization of richly diversified portfolio of indigenous grains.

The nutritional implications and resource efficiencies are substantial. Finger millet contains calcium concentrations nearly 30 times higher than milled rice. Pearl millet provides substantially elevated iron, zinc, and B-complex vitamins. These crops also exhibit low glycemic indices, which is particularly relevant given that India has an estimated 11 crore people living with diabetes. Moreover, millets require approximately 30 percent of water needed for rice cultivation, thrive in marginal soils with minimal chemical inputs, and generate lower greenhouse gas emissions. From ecological standpoint, resource demand associated with rice-wheat monocultures substantially exceed those of diverse indigenous grains.

India has initiated substantive interventions addressing these imbalances. The successful advocacy for declaring 2023 as the International Year of Millets through the United Nations represents strategic positioning of traditional crops within global nutrition discourse. Domestically, millets have been rebranded as *'Shree Anna'* (mother of all grains) to shift perception from coarse grains to nutritionally superior foods. Concrete policy measures demonstrate institutional commitment. Minimum Support Price mechanisms is now extending to minor millets and providing economic viability previously absent. The inclusion of millets in the Public Distribution System (PDS) and Integrated Child Development Services (ICDS) ensures institutional demand creation. Most significantly, the Pradhan Mantri Poshan Shakti Nirman (PM POSHAN) scheme incorporating millets into school meal programs reaches approximately 12 crore children, simultaneously addressing malnutrition and normalizing millet consumption for the next generation.

Although, challenges remain substantial. Reversing decades of policy orientation requires sustained commitment. Rebuilding supply chains and consumer preferences demands time. Traditional knowledge holders are also aging so knowledge scouting and documentation have become more urgent than ever. In this regard, NIF stands at the forefront to preserve and fortify indigenous and grassroots wisdom across length and breadth of the country.

The path forward embodies the principle of *Atmanirbharta* (self-reliance) rooted in indigenous strength. It necessitates the *Kartavya* (duty) of responsible stewardship and preserving knowledge systems refined across millennia for future generations. The vision of Viksit Bharat is *samruddhi* (collective prosperity) achieved through diversity, where nutritional adequacy and ecological balance define prosperity. ■

Dr. Arvind C. Ranade

At work with AI
- AI at work – learning by using

Nitin Maurya

Imagine sitting in a coffee shop with a friend who has read every book in the library but has rarely stepped outside. The friend is exceptionally articulate, capable of explaining quantum physics and even sharing a flawless dhokla recipe. Yet, when it comes to practical details-like finding the correct platform for a local train-they hesitate. Ask where the National Innovation Foundation–India (NIF)'s North India office is, and they might confidently say Dehradun, unaware that it relocated to NOIDA eighteen months ago. You correct the mistake; they acknowledge it. But step away, and the same error may surface again.

This captures the essence of interacting with Artificial Intelligence (AI). Public discourse often swings between portraying AI as near-magical or dismissing it as little more than an advanced search engine. In reality, engaging with-and learning from-AI is far more nuanced, blending impressive breadth of knowledge with occasional gaps in real-world context.

This article is based on the author's numerous conversations with Grok, ChatGPT, and Gemini that triggered the curiosity to understand their functioning. These three (and some others) are Large Language Models (LLMs) and advanced AI systems trained on massive datasets for various purposes. The article attempts to explain simply how AI "thinks," why it forgets and makes mistakes, and why your corrections are

useful for its future. The article concludes with a brief note on the use of AI models for generating content, commonly known as 'generative-AI'.

1. The "Short-Term Memory" problem

Talking to an AI is like having a conversation over a cup of chai. During the chat, the AI remembers what you say-this is called a "Context Window." Imagine a whiteboard where everything you and the AI say is written. The AI uses this information to be more helpful. Once you close the chat, the whiteboard is wiped clean. When you start a new chat, even minutes later, the AI treats you as a new person. Each session is a fresh start (unless things are marked for remembrance or chats enabled to be saved in an account). Why does AI work this way? Privacy. If AI remembered every personal detail from every user across sessions, it would pose a massive privacy risk. By forgetting, it stays a safe, neutral tool.

2. Why is AI wrong or can it be many times?

An AI's primary intelligence comes from its "training data"-a massive amount of human knowledge referred to at a specific point in time. Sometimes, an AI will give you an answer confidently but may be completely wrong. In the AI world, this is called a "Hallucination," meaning the AI produces information that sounds believable but incorrect.

AI does not know things the way a human does. If its "training

data" is from 2022, it might not have relevant and updated data from 2025. Imagine students who studied intensely for an exam in 2023 but did not update themselves. If you ask who won the 2024 general elections, they will "hallucinate" or guess based on old patterns because their "brain" is frozen with 2023 data.

3. If AI forgets, (why) should you correct it?

You might wonder: "If the AI is going to forget this chat anyway, why should I bother correcting its mistakes?" When you correct an AI, you are not just updating a database; you are compelling it to look for the right facts. Your correction prompts the AI to use its "live search" tools rather than relying solely on its "frozen" memory. Even though the AI bot might forget you or your conversations, your corrections are like a teacher's notes. These are used by Human Trainers and Developers to review conversations flagged as unhappy (the thumbs-down icon you click), or, if you corrected the AI, they are flagged internally for review by Human Trainers. Based on the inputs, the AI model gets "re-trained", with the result that it grows better for all users. You, thus, help to build a better tool for the whole community of users.

4. Can someone "Misguide" the AI with wrong data?

You may wonder if you can "teach" or "correct" an AI model-or if others can "feed" it wrong data. The AI uses a process

called Triangulation, comparing information from multiple sources for agreement before accepting something as fact. If a few people tell the AI, "The Qutub Minar is in Bengaluru," but its training and verified web searches show millions of references saying otherwise, it ignores those users. The AI seeks consensus and changes its "mind" only when evidence from trusted sources outweighs the noise.

5. What is your takeaway: You are the Captain

"Science is a good servant but a bad master" is an adage we grew up listening to. Similarly, AI is a powerful representation of human knowledge, but it does not "know" anything the way humans do. It analyses and predicts patterns, which you see in your conversations. You need to be smart to understand what you require, how to use an AI tool to obtain the data you sought out to. Always remember to cross-check any information provided by an AI. You should help it learn by using the "thumbs up" or "thumbs down" icons. Your correction today might help someone get the right answer six months or so from now.

Using AI for Content Generation

With the rapid growth of social media and AI tools in the post-pandemic era, countries worldwide have been facing challenges posed by Synthetic Generated Information (SGI), such as deep fakes, AI-generated research manuscripts, articles, and images. In 2025, both Indian regulations (the IT Rules 2025 Amendment[i]) and global academic standards (like APA 7th Edition[ii] and MLA 9th Edition[iii]) have moved towards a "Transparency-First" model. Essentially and ethically, the most important thing is to let readers know whether the entire content or any part of it was generated by an AI. If more than 10% of a video or audio is AI-generated, it requires a label. The same is applicable to an AI-generated image.

As mentioned earlier, an AI model can "hallucinate," hence the user must take complete responsibility for the facts and verify the details of the textual content generated. The AI does not have any legal standing, cannot be held accountable for its content, and cannot be listed as a "Co-Author." If the AI's response forms the core of an article, it is a standard practice to mention that the content was generated in response to specific prompts. This disclosure can be made at the bottom of the article, as this author has done. For formal citation examples, the web links provided in the last two endnotes may be referred to.

Purely AI-generated content is not eligible for copyright protection, as copyright laws require a human author or creator. However, since you provide specific prompts, generate content, review, and do the final editing, the Copyright of the final article belongs to you, not
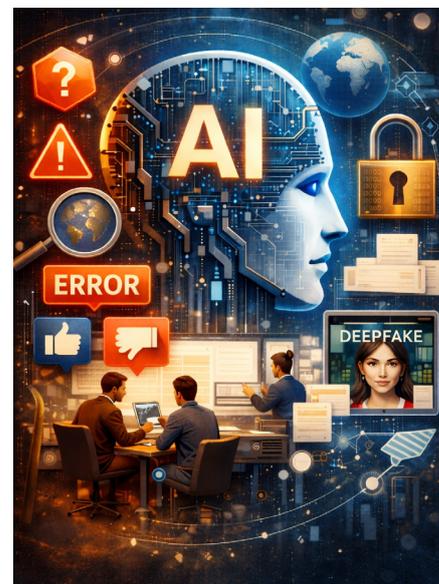
AI Generered Image

the AI developer. This is with the assumption that the final content establishes sufficient human authorship. But the Copyright issues are complex and vary from country to country. It is advisable to rely on human intelligence to ethically and wisely use AI tools for getting various tasks done, specially using the generative-AI.

Author's Disclosure:

This article was developed through a "Human-in-the-Loop" collaborative process with Google's Gemini AI. The author provided the context and prompts to generate content, which was compiled into this article, simplified and structured for flow. Some phrases and sentences from AI-generated content have been retained. The factual information was verified by the author. The final manuscript was reviewed and edited by the author to ensure accuracy and integrity. No copyright is claimed on the content, in part or full. ■

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Behind the Screen
- How AI Learns, Predicts, and Gets Things (Mostly) Right

Rintu Nath

When we interact with certain forms of Artificial Intelligence, particularly systems like chatbots, it feels conversational-almost human. We ask questions, receive fluent answers, and sometimes even creative metaphors in return, just like your friend will do in a conversation! If you prolong a discussion with a conversational AI interface, it may even reward you with sentences like " Great catch -you're absolutely right to flag this". Try to show inconsistency or mismatch in the conversation, it may write "You're thinking exactly like an editor here" with a thumbs up icon. But beneath this smooth interface lies a very different kind of "thinking", one that is statistical rather than conscious, predictive rather than experiential.

To truly understand both the remarkable capabilities and the clear limitations of AI, it is essential to look beyond the interface-examining how these systems are trained, how they generate responses, where they excel, where they fail, and why many common assumptions about "machine intelligence" can be misleading.

It is important to note that this conversational behaviour applies only to specific AI systems; most AI operates silently in the background, analysing data and making predictions without any human-like interaction.

AI Does Not Think-It Calculates Probability

At its core, a conversational AI system like ChatGPT, Gemini, or Grok does not know facts. Instead, it predicts the most likely next word based on patterns learned from vast amounts of text. When you type a sentence, the AI is essentially asking itself:

"Given everything written so far, what word is statistically most likely to come next?"

> **Behind the screen lies a very different kind of "thinking", one that is statistical rather than conscious, predictive rather than experiential**

This process repeats thousands of times per response. The result feels coherent because human language itself is highly patterned. Grammar, idioms, and logic all follow structures that machines can learn to imitate remarkably well. This process happens iteratively, token by token, allowing the system to produce responses that appear coherent, reasoned, and context-aware-despite the absence of understanding, intent, or verification.

This is why AI can sound confident even when it is wrong. Confidence is not awareness-it is simply a high probability score.

Training: Where AI Gets Its 'Worldview'

Before an conversational AI ever talks to users through its public interface, it goes through a training phase that can take months and enormous computing power. During training, the model processes trillions of words from books, articles, websites, code repositories, and other licensed or publicly available sources. Two key things happen during training:

Pattern Learning

The model learns how words, phrases, and ideas relate to each other across contexts.

Weight Adjustment

Billions of internal parameters (called weights) are adjusted to reduce prediction errors. This is done using techniques like backpropagation and gradient descent-methods that iteratively improve accuracy.

During training, the model makes a prediction and then compares it with the correct answer. The difference between the two is treated as an "error." This error is then traced backward through the system to identify which internal connections contributed most to the mistake-a process known as backpropagation. Once these weak points are identified, the

model makes tiny adjustments to them.

Gradient descent is simply the rule that guides these adjustments. Think of it as walking downhill in small, careful steps until you reach the lowest point. Each step slightly reduces error, and over millions of such steps, the model gradually becomes more accurate.

Once training ends, the model becomes static. It does not automatically update itself with new events, discoveries, or office relocations unless connected to external tools like search.

Why AI Sounds Reasonable Even When It's Wrong

Humans reason from experience and grounding in the physical world. AI reasons from textual correlations.

If many documents say, "X usually follows Y," the AI will assume that relationship holds-even if the context has changed. This is why AI can confuse outdated information with current reality, mix up similar entities, generate plausible but fictional details.

Technically, this is not "lying." It is pattern completion without verification.

Context Windows: The Limits of Attention

Every AI conversation operates within a finite context window-a limited span of recent text it can "see" at once. Within that window, the model can track references, follow logic, and maintain coherence. Once the window is exceeded earlier details may be truncated (deletion of least recent used data), or subtle constraints can be forgotten (shifting weights, change of priority) and as a result, answers may drift.

Statistical Triangulation

Statistical triangulation is not a single algorithm or a formal step inside an AI system. It's a useful way to describe how modern AI models arrive at reliable answers without "knowing" facts.

Think of it like this - Imagine you're trying to find the correct location of a mountain peak, but instead of one map, you have thousands of imperfect maps. Each map may have small errors, but if most of them place the peak in roughly the same spot, you gain confidence that the location is correct. You are not trusting any single map-you are trusting the overlap among many. AI works in a similar way.

During training, a model is exposed to enormous amounts of text from books, articles, manuals, encyclopedias, and other sources. It does not store facts as a database. Instead, it learns statistical patterns like, which statements tend to appear together, which explanations repeat across contexts, and which claims are consistently supported rather than contradicted.

When the same information appears again and again across diverse sources, the statistical signal becomes strong. When a claim appears rarely, inconsistently, or only in narrow contexts, the signal remains weak.

This is what we loosely called statistical triangulation.

The model infers reliability by cross-checking patterns across its entire training distribution, not by believing a single voice.

This is why a few users insisting that "the Taj Mahal is in Delhi" will not override millions of references placing it in Agra. Conspiracy theories struggle to become default answers unless they achieve massive, sustained repetition.

AI outputs often reflect mainstream consensus, even when no explicit rule tells them to do so.

This limitation explains why long conversations sometimes degrade in quality and why structured prompts often produce better results than casual ones.

Does Corrections Matter?

When users correct AI outputs, several things may happen behind the scenes. When you correct an AI during a conversation, your correction becomes new input in the same context window. The model then generates another response by looking at all previous text in that session, including your correction. In doing so, it actually updates probability weights, not beliefs. The model does not discard a "belief", even if you say that is "wrong" (read "belief" as statistical high probability event). Instead, it recalculates which next words are now more statistically likely, given your correction, the earlier question, and the surrounding context.

Importantly, AI improvement is population-based, not user-based. One person's correction helps improve future versions of the system, not the current one's "memory."

Think of it less as teaching a student and more as contributing data to curriculum reform, subject to rigorous authentication and validation process. Individual user inputs are not used directly as training data for conversational AI systems. This design safeguards the model from being influenced by incorrect, biased, or malicious inputs from any single source.

Consensus, Not Authority, and No Bias (ok, almost)

AI systems rely heavily on consensus signals. Information repeated across reliable, diverse sources carries more weight than isolated claims. This is why misinformation struggles to permanently alter AI outputs unless it becomes widespread and persistent.

Behind the scenes, the system relies on what can be thought of as statistical triangulation. During training, the model learns which facts, explanations, and associations tend to co-occur across large, diverse datasets. When multiple sources converge on the same idea, that pattern is reinforced. When claims conflict, the model favours the version that appears more consistently, across contexts and over time.

When live tools or retrieval systems are used, a similar principle applies. The AI does not "trust" one website or voice; it compares signals from many sources and looks for agreement.

A claim repeated across reputable outlets is treated as more reliable than one appearing in isolation.

That said, consensus is not the same as truth. If a bias or error becomes widespread in the data-through repetition, historical imbalance, or systemic blind spots-the model may reflect it. This is why AI outputs are generally robust against random misinformation, yet still imperfect mirrors of the world we feed into them.

In short, AI doesn't verify facts-it detects convergence.

Where many independent sources point in the same direction, the model follows the signal.

The Human Role: Prompting as a Skill

As conversational AI interfaces become more capable, a new literacy emerges: prompt literacy. Effective users specify context clearly, define constraints explicitly, ask follow-up questions, and most importantly, validate outputs independently.

In practice, the quality of AI output often reflects the quality of human input. The human remains the system's anchor to reality.

From Tool to Partner-With Guardrails

Many of us benefit from artificial intelligence, often without realising it-through search engines, navigation systems, language tools, and decision-support platforms. Used responsibly, AI can enhance efficiency, creativity, and access to information. However, presenting AI-generated output as one's own original work crosses an

> **The future of AI use is not about replacing human judgment. It is about augmenting it, while keeping accountability, ethics, and verification firmly in human hands**

ethical line. This concern becomes particularly serious in academic and research settings, where there have been reports of research papers being substantially written by AI systems. Such practices undermine scholarly integrity, erode trust in scientific communication, and risk propagating errors or fabricated information that may go undetected. Since AI systems can generate fluent but incorrect or misleading content, uncritical reliance on them in research can have far-reaching and even harmful consequences. Ethical use of AI therefore demands transparency, human oversight, and clear accountability for all claims, interpretations, and conclusions.

AI is neither an oracle nor a mere calculator. It is a powerful amplifier of human intent, capable of accelerating research, creativity, and decision-making-but only when guided responsibly.

The future of AI use is not about replacing human judgment. It is about augmenting it, while keeping accountability, ethics, and verification firmly in human hands. In the end, AI does not replace thinking. It challenges us to think better. ◼

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Grassroots Innovations (GRI) convergence with Artificial Intelligence (AI)

Tushar Garg

The year 2026 is significantly different from preceding years in multifarious ways, amongst which expectations from Artificial Intelligence (AI) i.e. How differently it is going to touch our nation, economy, lives, businesses and careers will be absolutely critical. In the context of our Bharat, it is even more important for a fact that New Delhi will host the AI impact summit , the first-ever global AI summit in the Global South during February 19 - 20, 2026. Bharat has chosen the theme of "Sarvajana Hitaya, Sarvajana Sukhaya" i.e. welfare for all, happiness for all for the summit.

In the most recent edition of World Economic Forum (WEF) 2026 at Davos , Hon'ble Union Minister for Electronics and Information Technology Shri Ashwini Vaishnaw, reiterated that Stanford places India third globally in AI penetration, AI preparedness and AI talent. Therefore, India is in top tier of AI economies, not second rung as noted by the International Monetary Fund (IMF) representative.

For the past few centuries, Industrial revolution has defined the scientific and technological development landscape of the world, and during 20th Century this was well augmented by innovations and in the ongoing 21st Century it is being led by Artificial Intelligence (AI). In other words, Science - Technology - Innovation (STI) and now Artificial Intelligence (AI) collectively define an eco-system which is absolutely necessary for the world. In this pursuit, two ideas must prevail :

- India should continue to be the foremost nation contributing to AI in some form or the other

- As much as AI complement Science and Technology based Innovations, Grassroots Innovations must ensure that they don't miss the bus and instead march hand-in-hand with AI led Industrial Revolution

While the former is being taken care by country's start-ups and broader industry, onus for the latter is on specialized institutions like the National Innovation Foundation (NIF) of India, which focus on the niche area called Grassroots Innovations and is already leading its eco-system for a good 25+ years.

From the lens of the National Innovation Foundation (NIF), the Grassroots Innovations encompass unaided technological innovations and traditional knowledge developed at grassroots by anyone without any professional / technical training or science / technology / R&D related education / work .

Dr. Mark Esposito, a renowned public policy scholar and social scientist affiliated with the Harvard Kennedy School in the India Innovation Index 2021 released by NITI Aayog noted as below -

"To tap into the country's technological potential, the first group to be identified and supported should be the grassroots innovators. The grassroots innovators are the people who have put to use traditional knowledge and developed indigenous technology. The traditional methods and systems of land are best in bringing efficiency to their production mechanism and the infrastructure. A farmer in Rajasthan would know the terrain of his land better to find innovative irrigation methods rather than using the same irrigation systems as the rest of the country. The necessity for maximizing profits for survival and efficient systems drives one to innovate. Supporting such innovations spreads knowledge and provides a competitive edge in the economy."

Holistically looking at India's approach to Grassroots Innovations through its Public Institutions like NIF and global approach as outlined by Dr. Mark Esposito, it is quite evident that grassroots innovations focus on bringing efficiency to production and infrastructure. And, this is

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2. https://www.business-standard.com/economy/news/wef-2026-india-top-tier-ai-economy-vaishnaw-davos-imf-126012100970_1.html

a shared objective for Artificial Intelligence (AI) as an emerging technology too. This can lead us to inference that as much as AI is important for everything else, it is also desirable for value addition to grassroots innovations. Though AI in general stems from those with a professional background, but software development related to AI and using AI i.e. it's adoption as a technology by end users are completely different phenomenon. For the latter i.e. AI adoption, there is no need for one to be formally trained or qualified. As an analogy, smartphone revolution adoption has included everyone; at least a wide majority of the world's 8 billion people, and has successfully proven that technology is the biggest equalizer ever. Likewise, there is no reason why AI can't be a part of GRI's eco-system. The use cases will vary significantly though - at times, it could be innovators adopting AI for validation, value addition, research and development etc, and also for improving productivity of their enterprises. This will trigger important changes like improving TRLs (Technology Readiness Levels) in-situ and prior to incubation which means that when institutions like NIF will scout, hand-hold and nurture such innovations, they could be more refined and minimally crude as compared with present scenarios.

Artificial Intelligence (AI) is increasingly seen as a trend, which is here to stay and not as a bubble,

AI Genereted Image

and it is poised to make the universe more efficient in terms of operations being performed and GRI's and their incubation is no exception. It has the potential to show impact not just in a linear fashion, rather exponentially too, given an opportunity. It also demands that everything and anything being executed should necessarily have its data preserved and will lay foundation of a greater data discipline for GRI's which can define its progress in a more vibrant manner than ever before. The AI world have a lot of expectations from India primarily for country's huge data volume generation abilities and simultaneously a vast engineering talent waiting to be harnessed in the revolution. A large amount of such data sources are at the grassroots and once we capture it, India will be able to offer edge like no other economy could. The Government of India through FY

2026-27 Union Budget has laid a huge emphasis towards building a state-of the-art ecosystem to support AI in India. With the support of grassroots innovation eco-system, which NIF has proudly built during last 26 years, India will be able to capitalize upon the inclusivity dimensions of AI. Such approaches will ensure rural progress and help bridging the rural-urban divide by handholding grassroots tech deployment nationwide as noted in the Economic Survey 2025-26 through initiatives like Rural Technology Action Group (RuTAGe) Smart Village Centre (RSVC). There is a clear opportunity to have many more initiatives like these implemented in the country, or achieve more from these existing initiatives with the added element of AI which can not only help scale be achieved sooner but also on a much wider scale than ever before. ◼

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Relevance of herbal knowledge system for sustaining health care
- A specific reference to drug development based on herbs

Hiral Gadhavi, Akshay Kumar Lunawat, Panchsheela N, and Ravikumar R K

The development of new drugs is essential to address the persistent limitations and challenges associated with existing healthcare products. Central to this process is the identification of promising lead compounds for evaluation within the drug development pipeline. In this context, plant-based compounds have received significant attention, as herbal preparations have long formed an integral part of therapeutic practices.

The functional properties of medicinal herbs have been explored continuously throughout human history, and their use in healthcare and production systems has been deeply embedded in civilization. Traditional medical practices evolved through empirical observation, societal needs, and environmental influences, aligning closely with cultural beliefs and recognized pharmacological effects. Over time, these practices were sustained and disseminated across wide geographical regions.

Herbal resources constitute a core component of these accumulated experiential systems, resulting in a vast repository of traditional knowledge. This rich heritage has led to the compilation of numerous herbal pharmacopoeias. Importantly, natural products derived from medicinal plants have demonstrated significant potential as sources of bioactive compounds and precursors for modern drug discovery and development.

The relevance of herb to provide new compounds is well documented and several criteria's were engaged in their selection. This include scientist identifying therapeutic effect by assessing folklore practices like isolation of active principle salicin-a salicyl alcohol glucoside in the year 1828 [Raskin, 1992]. This compound was obtained from willow tree (Salix spp.) and led to commercial production of salicylic acid by 1874 [Raskin, 1992]. This approaches illustrate that naturally derived phytochemicals can be precursors thereby allowing refinement, development of new drugs. These phytochemicals are secondary metabolites synthesized by plants and are not directly involved in primary metabolic processes like photosynthesis. However they are essential for plants in functions like defence and employed in industrial applications *viz.*, medications, pesticide, cosmetics. This had generated continued interest in their investigation on structure and therapeutic application(s). These compounds are produced by plants in small quantities making it a limiting factor as well.

Secondary metabolites are a diverse group of organic compounds. They were grouped into three major categories based on their chemical structure and biosynthetic origin. These categories include Alkaloids, Phenolic compounds and Terpenoids. This classification reflects both their structural complexity and biological activity, widely accepted in pharmacognosy and natural product chemistry. Other compounds such as flavonoids, tannins, glycosides, saponins, quinones and sulphur containing compounds (like allicin) are considered subclasses or derivatives within these major groups rather than independent classes.

Alkaloids represent one of the most therapeutically important groups possessing basic nitrogen atoms (alkaline chemicals), term coined in 1819 [Dey et al., 2020].
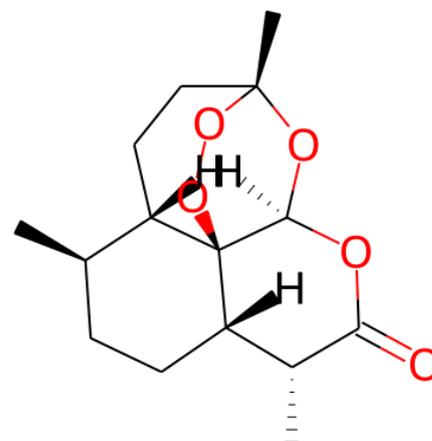
Phytochemical: 3-D structure of Artemisinin
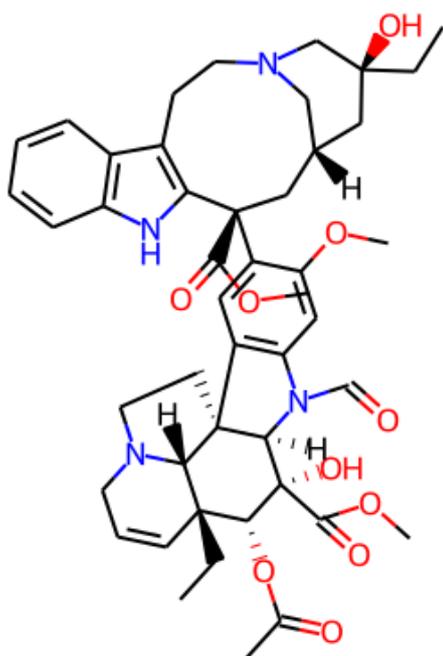
Phytochemical: 3-D structure of Vincristine

Plant-derived alkaloids such as atropine, morphine, quinine, vincristine, and vinblastine have long been used in modern medicine. For example, atropine from *Atropa belladonna* acts as an anticholinergic agent, morphine from *Papaver somniferum* remains a standard molecule of analgesic in pain management. Quinine obtained from *Cinchona* has historically played a vital role in treatment of malaria and continues to inspire antimalarial drug development [Gachelin et al., 2017].

Phenolic compounds form an important class of secondary metabolites extensively studied for their antioxidant and anti-inflammatory activities with a hydroxyl group (-OH) connected to an aromatic ring. Compounds such as curcumin, quercetin, kaempferol, and capsaicin demonstrated therapeutic role management of chronic diseases like cancer, cardiovascular disorders, neurodegenerative, arthritis and diabetes. These molecules exert their effects by modulating oxidative stress, inflammatory signalling pathways and cellular survival mechanisms. They are generally recognized as safe. Further, wide availability from dietary sources enhance their appeal as therapeutic, nutraceuticals agents and as functional foods [Ansari et al., 2025]. Flavonoids, another subclass of phytochemicals related to polyphenol were found in fruits, vegetables playing role in protecting cells from free radical damage.

Terpenoids are major group of secondary metabolites with extensive therapeutic potential having isoprene molecule as their structural identity. Artemisinin, a sesquiterpene lactone derived from *Artemisia annua*, is one of the most effective antimalarial drugs, World Health Organization recommended Artemisinin Combination Therapy (ACT) to treat drug resistant malarial parasite in the year 2005 and saved millions of lives. Beyond malaria, artemisinin and its derivatives exhibit anti-inflammatory, antiviral, anticancer and immunosuppressive properties, demonstrating broad pharmacological actions [Lee et al., 2023].

Other compounds:

Cardiac glycosides such as digoxin from *Digitalis lanata* are essential in management of heart failure and arrhythmias due to their cardiotonic effects. Cyanogenic glycosides, found in over 2600 plant species, are used in treatment of cancer; saponin from *Acacia concinna (shikakai)* is utilised as a natural surfactant. Essential oils are highly volatile plant secondary metabolites, which have diverse molecules like terpenes, phenolics, alcohols, and aldehydes. These metabolites have properties of defence, stress response, aroma and used in food, medicine, cosmetics.

Research need in drug development derived from phytochemicals:

Alkaloids such as Atropine, Quinine, Colchicine, Galanthamine, Nicotine, Vinblastine and Vincristine were isolated and confirmed for their medicinal use. Similarly, phenolic compound Capsaicin isolated in 1816 has been in use for its medicinal value in the form of generic product Zostrix. It was observed that more than 50,000 secondary metabolites were characterized from plant sources (Teoh, 2015). About 25 percent of medicinal remedies being used in the current health system were derived from plant and an estimate of 121 phytochemicals are in usage (Rates, 2001). Certain breakthrough drugs derived, based on properties in herbal folkloric knowledge were illustrated along with their pharmacological actions (Table 1).

> **Cardiac glycosides such as digoxin from Digitalis lanata are essential in management of heart failure and arrhythmias due to their cardiotonic effects**

The early medical writing (1250) of Welsh family of physicians (Physicians of Myddvai) and high frequency of usage of plants helped in development of valuable drugs like Digoxin and Artemisinin

Table 1 Development of drugs based on properties derived from herbal knowledge system

S N.	Drug name	Plant	Secondary metabolite	Isolated by	Generic Product	Pharmacological activities
1	Atropine	*Atropa belladonna* (Belladonna)	Alkaloid	Heinrich F. G. Mein [1832]	Atropine Sulfate Ophthalmic Solution, USP 1% [1995]	Anticholinergic agents
2	Quinine	*Cinchona officinalis* (Cinchona)	Alkaloid	Pierre Joseph Pelletier and Joseph Caventou [1820]	Dr. Sappington Anti-Fever Pills [1832]	Anticancer, antioxidant, antidiabetic, antifungal, muscle cramps, hair growth stimulant, antiviral, anesthetic, antimalarial and antipyretic
3	Artemisinin	*Artemisia annua* (Sweet Wormwood)	Sesquiterpene	Tu Youyou [1972]	Artesunate [1987]	Anti-malarial, anti-cancer, anti-inflammatory, anti-viral and anti-parasitic
4	Capsaicin	*Capsicum annuum* (Red pepper)	Phenolic compound	Christian Friedrich Bucholz [1816]	Zostrix [1986]	Analgesic, anti-inflammatory, antioxidant, anti-obesity
5	Colchicine	*Colchicum autumnale* (Autumn crocus)	Alkaloid	Pierre-Joseph Pelletier and Joseph Bienaimé Caventou [1819]	Colcrys [2009]	Anti-inflammatory
6	Digoxin	*Digitalis lanata* (Grecian Foxglove)	Cardiac glycoside	Dr. Sydney Smith [1930]	Lanoxin [1954]	Cardiotonic
7	Galanthamine	*Galanthus nivalis* (Snowdrop)	Alkaloid	Mashkovsky [1950s]	Nivalin [1959]	Improving memory
8	Nicotine	*Nicotiana tabacum* (Tobacco)	Alkaloid	Wilhelm Heinrich Posselt & Karl Ludwig Reimann [1828]	Nicorette [1978]	Improves cognitive function
9	Vinblastine	*Catharanthus roseus* (Periwinkle)	Alkaloid	Robert Noble and Charles Thomas Beer [1958]	Velban [1961]	Anti-cancer
10	Vincristine	*Catharanthus roseus* (Periwinkle)	Alkaloid	Charles D. Carmichael and Harold P. S. Harington [1950]	Oncovin [1963]	Anti-cancer

A significant contribution by accessing herbal based traditional practices resulted in screening and development of drug precursors

respectively. In Greece, belladonna (atropine) was traditionally used to dilate pupils, in control of fever cinchona bark (quinine) was used in Peru and Sweet wormwood (artemisinin) in Chinese traditional system of practices. Autumn crocus (Colchicine) was used as herbal remedy for joint pain in Egypt, Grecian foxglove (digoxin) used for treatment of heart related ailments in Wales, United Kingdom. Tobacco (Nicotine) was used by native Americans for overcoming intestinal symptoms. Nicotine-containing herbs were used by communities in regions of Cuba to reduce fatigue and to sustain alertness. Red pepper (capsaicin) was known for its culinary role in South America and referred to treat sore throats, cough. Snowdrops (Galanthamine) was used to treat poliomyelitis symptoms in Ural mountain regions of Russia.

These features illustrates importance of documentation of folkloric knowledge system, validity of herbs which are commonly used and advancement of drug precursors from medicinal plants. Folk medicine is an essential part of healthcare systems worldwide. It was the foundation of healthcare system until modern drugs were developed. A significant contribution by accessing herbal based traditional practices resulted in screening and development of drug precursors. This had facilitated administration of drugs in specific dosage without influence of age of raw materials or source of it. Modern scientific facilities helped to confirm and nurture herbal knowledge system for sustainable health care. ■

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Organic Agriculture in India
- Current Status, Opportunities, and Challenges

Mohd Arshad Siddiqui, Hardev Choudhary

Introduction:

Organic farming has emerged as a significant force in contemporary food systems, propelled by growing concerns over environmental degradation, food safety, and the sustainability of agricultural practices. At its core, it is an ecological approach to farming that excludes synthetic fertilizers, pesticides, genetically modified organisms (GMOs), and growth hormones, and instead emphasizes natural processes, biodiversity, and soil health for nutrient management and pest control. With increasing demand for healthier and environmentally responsible food choices, organic agriculture is expanding rapidly, evolving from a niche practice into a broadly supported and mainstream approach embraced by farmers, consumers, and policymakers worldwide.

Organic farming emerged in the early 20th century, a time when rapid industrial growth was transforming agricultural practices. For generations, farmers had relied on methods like crop rotation, composting, integrated livestock farming, and natural pest control. But following World War I, the development of synthetic fertilizers and chemical pesticides dramatically changed agriculture, allowing food to be produced on a much larger scale. Although this early 'Green Revolution' boosted crop yields, it also led to negative side effects, including deteriorating soil quality, chemical residues in food, polluted waterways, and a loss of biodiversity.

Today, organic farming is widely acknowledged as a key approach to achieving sustainable food production. Contemporary organic systems blend traditional practices with scientific advancements, such as biological pest management, renewable energy use, and studies of soil microbiomes, showing that environmentally responsible agriculture can also be economically successful.

Status of Organic Agriculture in India:

Madhya Pradesh, Maharashtra, Gujarat, and Rajasthan are the top contributors in terms of organic-certified farmland, collectively representing a major portion of India's organic agriculture. Sikkim is notable as well it stands out as the country's first completely

Bio-decomposition of organic wastes (Vegetable market waste, Food waste & Farm yard manure) for the production of compost and vermicompost

Table-1: Key figures of Indian organic agriculture

Indicator	Latest / Recent Data	Comments / Context
Total organic-certified area	10.17 million hectares (as on 31 Mar 2023) under National Programme for Organic Production (NPOP) - includes ~5.4 mha cultivable land + ~4.7 mha wild-harvest area	Reflects broad coverage — not just farmlands but also wild-harvested organic produce
Area under cultivation (organic + conversion)	As of 2023–24: several sources report ~6.4 million ha under cultivation (including conversion lands) under organic certification	The "conversion area" indicates land transitioning to full organic standards
Number of organic producers	~1.6 million registered under certification (2021/22) per APEDA	India reportedly has the highest number of organic producers globally
Production (certified organic products)	~2.66 million metric tons (farm production under NPOP, as per latest APEDA data)	Includes a variety of crops: cereals/millets, pulses, oilseeds, fibre (cotton), medicinal plants, fruits/vegetables, spices, etc.
Organic exports (2022–23)	~312,800 tonnes; export value ≈ ₹5,525.18 crore (≈ USD 708.33 million)	Export markets include USA, EU, Canada, UK, Switzerland, Australia, Japan, Korea, Vietnam, etc.

organic state, with all of its farmland managed under organic methods. Although organic farming is practiced across India, it remains concentrated in a handful of states, indicating considerable potential for growth in regions that are currently underrepresented.

State-wise Distribution:

In 2023-24, the distribution of certified organic and in-conversion agricultural land in India is heavily concentrated in a few states:

Madhya Pradesh: ~6.13 lakh ha organic + ~5.35 lakh ha in conversion, totalling ~11.48 lakh ha

Maharashtra: ~2.67 lakh ha organic + ~7.34 lakh ha in conversion, totalling ~10.01 lakh ha

Rajasthan: ~2.15 lakh ha organic + ~3.65 lakh ha in conversion, totalling ~5.80 lakh ha

Gujarat: ~0.92 lakh ha organic + ~5.88 lakh ha in conversion, totalling ~6.81 lakh ha

Together, these four states represent roughly 76% of India's total organically farmed area. A smaller but noteworthy case is Sikkim, India's first fully organic state, with ~75,472 ha of certified organic land.

Trends & Future Potential:

India is increasingly prioritizing sustainable and organic farming, driven by concerns about soil health, biodiversity, and rising consumer demand for chemical-free food. With millions of farmers and a wide range of agro-ecological regions, the country has substantial room to expand organic agriculture, both across new states and districts and through a broader mix of crops and products. There is also strong potential to boost exports and develop value-added organic goods through processing, packaging, and certification, particularly in areas where India already holds an advantage, such as cotton, spices, pulses, and medicinal plants. Organic agriculture also aligns well with traditional farming practices, indigenous knowledge,

Figure-1: Indian states showing percentage of net sown area under organic farming (Source: iasgyan.in)

India's organic farming sector has witnessed significant growth, with the country now hosting the largest number of organic producers globally

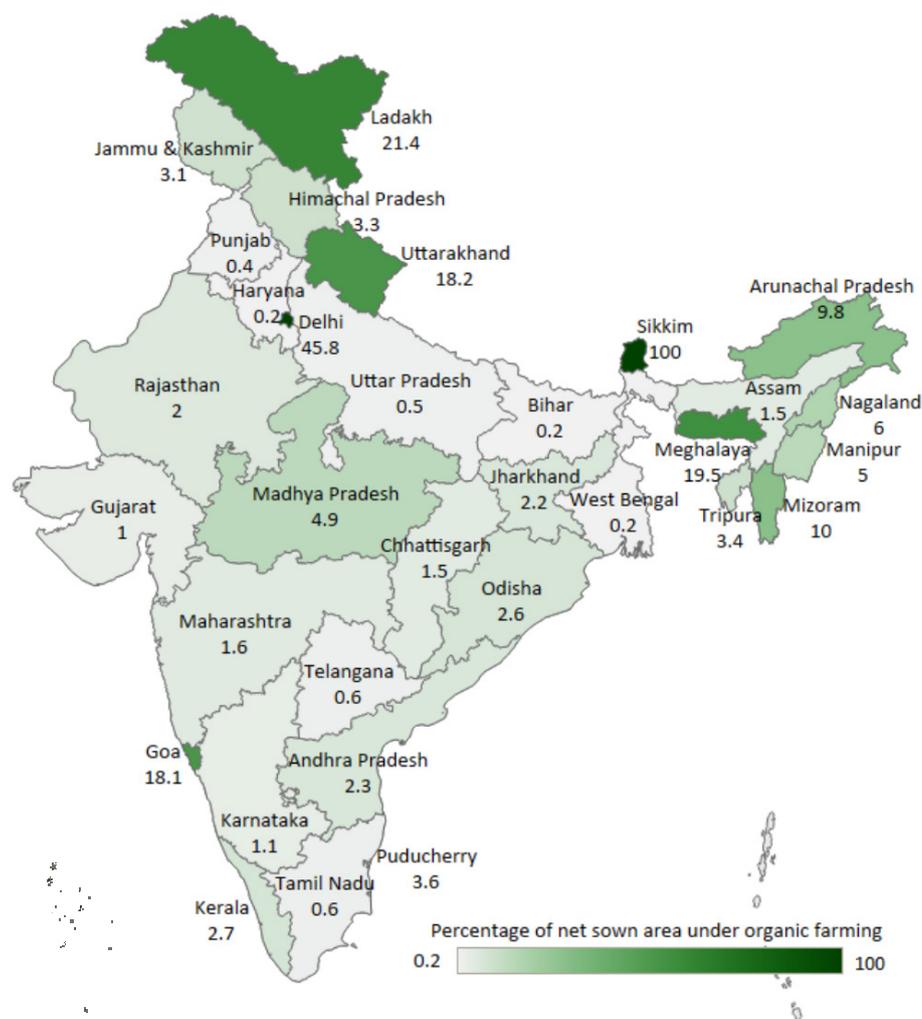number of organic producers globally and several million hectares under certified organic cultivation. Despite this progress, organic agriculture continues to occupy only a limited proportion of the total agricultural area. Considering India's diverse agro-ecological regions, increasing domestic and international demand, and supportive policy environment, the potential for further expansion of organic agriculture remains considerable and largely untapped. ▪

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biodiversity protection, and sustainable rural livelihoods, positioning it as an important long-term strategy for India's agricultural sector.

Challenges & Limitations:

Despite recent expansion, organically certified farmland still represents only a tiny share of India's total cultivated area, around 2% of the net sown area in 2020. Shifting from conventional to organic practices requires a multi-year conversion period, certification expenses, and the possibility of reduced yields at the start, which often discourages farmers, particularly smallholders. Limited market access, inconsistent pricing, supply-chain gaps, and low consumer awareness, especially outside major cities, continue to restrict domestic demand for organic products. Moreover, the sector's reliance on exports for profitability makes it susceptible to fluctuations in global markets and changes in international trade policies.

Summary:

In conclusion, India's organic farming sector has witnessed significant growth, with the country now hosting the largest

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Solar Ironing
- An Efficient, Sustainable, and Eco-Friendly Solution for Society

Vinay Kumar Yadav, Amit Jain, and Vinisha Umashankar

In an era increasingly defined by the pursuit of sustainable living, impactful innovation often lies in elegant simplicity. One such grassroots solution is the Solar Iron, a practical and environmentally responsible alternative to conventional ironing methods. By harnessing solar energy, this innovation addresses two critical challenges-unreliable electricity supply in rural and semi-urban areas and the growing concern over carbon emissions associated with conventional energy use.

The concept originated when a 14-year-old school student from Thiruvannamalai, Tamil Nadu, proposed the idea of a solar-powered ironing cart to the National Innovation Foundation (NIF). Recognizing the promise and social relevance of the idea, NIF took the initiative forward, refining and developing it into a robust, scalable, and impactful solution. Today, the Solar Iron stands as a testament to how youthful creativity, when supported by institutional expertise, can translate into meaningful innovation for sustainable livelihoods.

A Game-Changer for Street Side Ironing Vendors

The traditional ironing system used by street-side ironing vendors (iron wallahs) or small business owners primarily relies on coal or electric-powered irons. These methods not only contribute significantly to carbon emissions but also pose health risks to the vendors due to prolonged exposure to smoke and heat. Moreover, the rising cost of electricity and fossil fuels places additional financial strain on already vulnerable livelihoods.

The solar ironing solution directly addresses these challenges. At its core, the system comprises a solar panel mounted on a portable frame and connected to an electric iron. By harnessing solar energy, the system eliminates dependence on charcoal and grid electricity altogether. This makes it particularly valuable in regions where power supply is unreliable or unavailable for extended periods.

With adequate sunlight, the solar ironing unit can operate independently throughout the day, ensuring uninterrupted work and consistent income. It can be a win-win outcome-significantly reducing environmental impact while enhancing the economic sustainability of ironing as a micro-enterprise.

Empowering Communities & Inspiring Change

The Solar Ironing system is rooted in a commitment to empower local communities while driving meaningful social and environmental change. In India, an estimated 10 million street-side ironing vendors depend on traditional charcoal-based irons for their livelihoods. On average, each vendor consumes nearly 5 kilograms of charcoal per day-amounting to approximately 1,825 kilograms annually. At scale, this translates into an enormous environmental burden, contributing significantly to deforestation, air pollution, and carbon emissions.
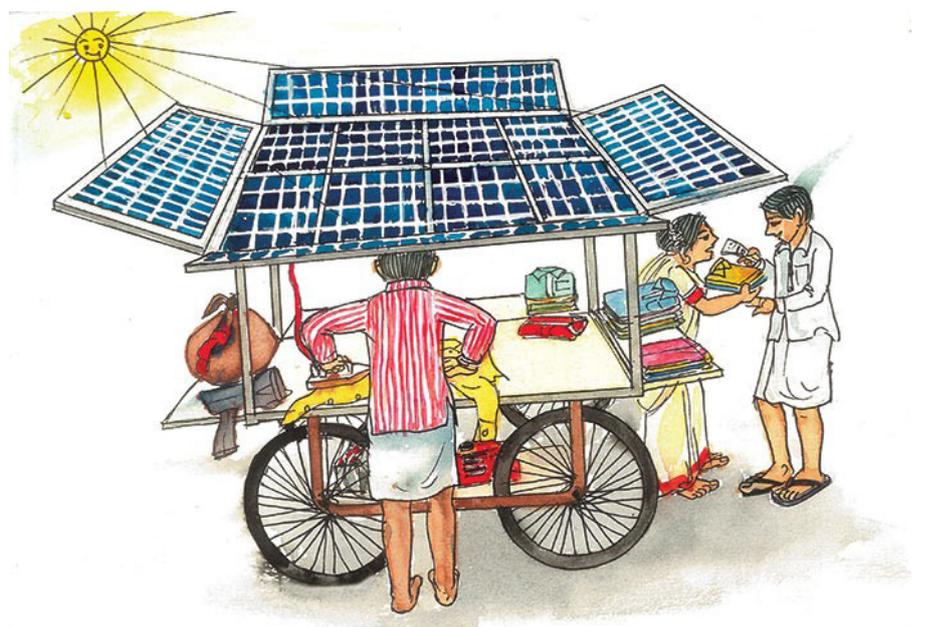
Idea of the project by schoolgirl

Solar ironing offers a practical and affordable solution to this challenge. With the average cost of fuel or electricity running irons reaching around ₹10 per unit equivalent, a single press wallah can save nearly ₹18,250 per year by switching to solar energy. Vendors who rely on grid electricity typically spend ₹4,000–₹5,000 per month on power bills, amounting to nearly ₹60,000 annually. For families living close to the poverty line, these savings are transformative-freeing up income for essentials such as housing improvements, healthcare, and children's education.

Beyond economic benefits, solar-powered ironing delivers substantial environmental gains. Burning one kilogram of coal releases approximately 2.5 kilograms of carbon dioxide (CO_2). By eliminating the daily use of 5 kilograms of coal, each ironing unit can reduce nearly 4.6 tons of CO_2 emissions annually. When adopted by 10 million vendors nationwide, this translates to a potential reduction of nearly 46 million tons of CO_2 each year.

Such large-scale emission reductions can significantly support India's climate commitments under international frameworks like the Paris Agreement. By combining livelihood security with clean energy adoption, solar ironing stands as a powerful example of how grassroots innovation can contribute to both social upliftment and national climate goals.

Direct DC Solar Ironing: Value Addition and Technical Innovation by the NIF Team

a) Background: Limitations of Existing Solar Ironing Solutions

Most currently available solar ironing carts rely on batteries and inverters to convert solar-generated DC power into conventional AC power (typically 230V) for operating standard electric irons. While functional, this approach introduces several drawbacks-namely power conversion losses of 10–20%, increased system complexity, higher upfront costs, and recurring expenses related to battery maintenance and replacement.

Recognizing these limitations, the NIF team developed an improved solution that directly utilizes solar DC power, eliminating unnecessary intermediaries and enhancing overall system efficiency.

b) Proposed Innovation: Direct DC Solar Ironing System

The proposed solution integrates a custom-designed, high-efficiency DC heating element directly into the iron, allowing it to be powered straight from solar photovoltaic (PV) panels. By bypassing the inverter stage, the system significantly improves efficiency, reliability, and affordability for end users.

c) Key Design Advantages

- Inverter Elimination: Removes AC–DC conversion losses, simplifies system architecture, and substantially reduces capital cost.

- Direct Energy Utilization: Solar power is delivered directly to the heating element, ensuring maximum thermal efficiency.

- Scalability: The system can be precisely sized to match the daily thermal and operational needs of a press wallah without excessive energy storage.

Conversion of Traditional Iron into Solar Iron

Instead of redesigning the iron from scratch, the innovation focused on retrofitting the existing professional iron, which is already optimized for weight, heat retention, and ironing quality. The objective was to make it solar-compatible while preserving its familiar form and performance.

For this purpose, the following steps were taken:

Step 1: Field Survey and Vendor Feedback

Local professional ironing vendors using 5–7 kg electric irons were surveyed. Inputs were collected on heating time, preferred operating temperature, daily usage duration, and openness to adopting solar-powered solutions.

Step 2: Power Requirement Assessment

It was observed that professional irons typically consume 900–1200 watts, but operate intermittently-remaining ON only about 50% of the time. This results in an average effective power requirement of 450–600 watts.

Step 3: Solar System Sizing

Based on the assessed load, a 670-watt solar PV setup was finalized, utilizing 2 × 335W solar panels. Depending on operational needs, an MPPT charge controller (24V or 48V) and an optional battery bank (lithium-ion or lead-acid) may be incorporated to support off-sunshine operation.

An Industrial iron

Solar iron tested by Professional

Data collection by the team

Step 4: Resistance Analysis

The resistance of the existing heating element was measured, and the required resistance for optimal solar DC operation was calculated.

Step 5: Custom Heating Element Design

The original AC-compatible nichrome heating element was replaced with a custom-designed nichrome DC heating element, precisely matched to the solar panel output for safe, efficient, and stable operation.

Challenges and the Road Ahead

Despite its strong potential, the widespread adoption of the solar ironing system faces several challenges. The initial cost of a solar ironing system-typically ranging between ₹20,000 and ₹25,000-can be prohibitive for many vendors without access to financial assistance. Limited awareness, along with a lack of training in operating and maintaining solar-based systems, further constrains adoption.

However, these barriers are not insurmountable. Targeted government support, corporate social responsibility (CSR) initiatives, and focused awareness campaigns can play a pivotal role in accelerating adoption. Integrating this innovation into rural electrification programs, skill-development initiatives, or small business support schemes could provide the momentum needed for large-scale deployment.

Collaboration among innovators, social entrepreneurs, policymakers, financial institutions, and environmental groups will be essential for scaling this solution. Pilot projects, capital subsidies, and buy-back or upgrade schemes for older carts can help build a robust circular economy around the product, ensuring long-term sustainability and affordability.

A Brighter, Cleaner Future

The Solar Iron System demonstrates that impactful sustainable innovation does not always require complex or expensive technology. Often, simple, context-driven solutions deliver the greatest social and environmental benefits. This clean-energy innovation enhances livelihoods, strengthens micro-enterprises, and reduces environmental harm-all simultaneously.

As both urban and rural India confront the twin challenges of energy insecurity and unemployment, solutions like this offer a tangible path forward. With the right policy backing and institutional support, solar ironing systems can transform the daily operations of millions of small vendors, making sustainability not just an aspiration but a practical, everyday reality.

Looking ahead, the system's portable setup enables vendors to operate across multiple locations, access high-footfall areas, and increase daily earnings-further strengthening its economic viability and long-term impact. ■

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Role of Grassroots Innovations in Viksit Bharat 2047

Rahul Prakash, Abinash Samal, and Vivek Kumar

Empowering India's Transformation Through Frugal Innovation, Inclusive Growth, and Sustainable Development

As India embarks on its ambitious journey towards becoming a developed nation by 2047, the centenary of its independence, a powerful yet often overlooked engine of transformation emerges from the grassroots-innovations born from the creativity, resilience, and indigenous knowledge of common people. These grassroots innovations (GRIs) represent solutions developed by common people using inherent creativity to solve local problems. While high-tech industries drive global competitiveness, GRIs ensure that development is inclusive, sustainable, and culturally rooted, reaching the 'last mile' where institutional support rarely penetrates.

A Roundtable on 'Role of Grassroots Innovations in Viksit Bharat 2047,' held on December 27, 2025 at the National Sanskrit University, Tirupati, during Bhartiya Vigyan Sammelan 2025, brought together innovators, policymakers, and academicians to deliberate on how these innovations can catalyze India's transformation. The discussions, facilitated by the National Innovation Foundation-India (NIF), revealed compelling narratives of innovation that deserve national attention. Four key themes emerged from these deliberations: democratizing development by empowering marginalized communities, harnessing the economics of frugal innovation, building environmental resilience through sustainable solutions, and nurturing the entrepreneurial spirit among India's youth.

Democratizing Development

Development, in its truest sense, must be democratized-accessible to all, owned by all, and beneficial to all. Grassroots innovations achieve precisely this by empowering rural communities, artisans, and marginalized groups who often remain bypassed by mainstream industrial growth. Unlike top-down approaches, these innovations emerge from within communities, addressing real problems with locally available resources and knowledge. They democratize the very process of development by making communities both creators and beneficiaries of technological progress.

The innovators present at the roundtable personified this philosophy of inclusive development. Padma awardee C.V. Raju from Vishakhapatnam, by reviving the dying art of Etikoppaka wooden toys among tribal communities, has not only preserved a rich cultural heritage but empowered over 200 artisans and created sustainable livelihoods for thousands of tribals. His chemical-free toys with minimal carbon footprint have the potential to significantly reduce India's dependence on imported plastic toys if diffused widely-a contribution recognized by Prime Minister Shri Narendra Modi in "*Mann Ki Baat.*" Similarly, Chintakindi Mallesham's Asu Making Machine transformed the lives of women weavers in Telangana by reducing the grueling 9,000 hand movements over one and a half days to just 1.5 hours, earning him the Padma Shri. Complementing this, Shiva Kumar Modha's Pedal Lifting Machine addresses knee pain issues faced by handloom weavers, enabling convenient weaving for the handicapped, women, and seniors. Together, these innovations demonstrate how grassroots solutions can uplift entire communities while preserving their cultural identity.

The Economics of Frugal Innovation

The economics of development often presents a challenging equation-how to deliver quality solutions at scale without prohibitive costs. Frugal innovation answers this question. India's emergence as a global leader in frugal innovation-developing high-quality solutions at minimal cost-is crucial for achieving development goals with low capital expenditure. This aligns perfectly with the Atmanirbhar Bharat vision, where self-reliance is built not through isolation but through affordable indigenous solutions that can scale across the country. Frugal innovation enables essential services to reach millions who cannot afford expensive alternatives, making it a cornerstone of inclusive economic growth.

Several innovations at the roundtable demonstrated how this principle translates into practice. D.N. Venkat's Multi Tree Climber enables farmers to climb 10-12 trees per hour safely at an affordable price; with over 10,000 units sold domestically and export to 30 countries. Alladi Prabhakar's Coconut Shredder converts waste coconut shells into valuable coco fiber and peat at approximately Rs. 1 lakh, bringing processing technology within reach of small-scale farmers. The Flower Tying Tool by Shri Manjunath, priced at just Rs. 2,500, enables 25 feet of garland production per hour, transforming traditional garland-making economics.

While affordability drives adoption, the roundtable discussions revealed that it alone does not guarantee sustained success. Sandip Vishram Ghole shared how he cracked the onion seed market in Madhya Pradesh through strategic distribution of free samples, redesigned branding, and continuous farmer engagement via WhatsApp groups. Jogendra Patra emphasized that servicing and warranty are instrumental in building trust, urging innovators to develop support networks similar to established companies. These insights underscore that innovation alone is not enough-market-readiness, user engagement, and after-sales support are equally critical for commercial success.

Innovation for Environmental Resilience

Environmental resilience cannot be imported-it must be built from within, using local knowledge and sustainable practices. As India commits to achieving Net Zero by 2070, the question arises: how can a developing nation balance economic growth with environmental responsibility? Grassroots innovations offer a compelling answer. Rooted in traditional knowledge and local materials, these solutions are inherently eco-friendly, providing a blueprint for sustainable living that neither burdens the environment nor the economy.

This was evident in the innovations presented at the roundtable. Girish Bhadragonda's Solar-Powered Chickpea Nipping Machine automates labor-intensive farming while collecting valuable leaves, powered entirely by a 100-watt solar panel. Jogendra Patra's Sal Leaf Plate and Bowl Making Machine promotes biodegradable alternatives to plastic. Ajay Kumar Prusty's Paddy Straw Cutter addresses stubble management-a critical environmental concern-by converting agricultural waste into mushroom cultivation substrate, with 1,400 units already sold in Odisha and Jharkhand.

Beyond machines, traditional knowledge holders play an equally vital role in building environmental resilience. Smt. Laxmibai Zulapi from Karnataka has conserved the HZKB-1 brinjal variety using organic pest control with poultry manure, neem oil, and cow urine. Prakash Singh Raghuvanshi's Kudrat 3 Pigeon Pea and Kudrat-9 Wheat varieties, developed through traditional selection methods, offer high yields with disease resistance. Kishan Suman's Sadabahar Mango, developed over fifteen years, fruits throughout the year. G. Chandrasekhar's herbal preparation for controlling root knot nematode provides eco-friendly pest management. Collectively, these innovations demonstrate that environmental sustainability and agricultural productivity can go hand in hand.

Nurturing the Entrepreneurial Spirit

Entrepreneurship begins with the courage to solve a problem and the conviction to see it through. For India to achieve its Viksit Bharat vision, it must nurture this spirit

among its vast youth population, transforming them from job seekers into job creators. This requires not just skill development but fostering an entrepreneurial mindset that identifies problems as opportunities. Grassroots innovations demonstrate that transformative ideas can emerge from anywhere-a school student's observation, a fabricator's workshop, or a farmer's field-provided the ecosystem nurtures such creativity.

The roundtable featured inspiring examples of such transformation in action. Young Sayen Akhtar Shaik, a school student from Andaman and Nicobar Islands, developed an LPG Cylinder Cap Opener after seeing his mother struggle-demonstrating that innovation can begin at any age. Jalendra Kumar, a 32-year-old fabricator from Bihar, evolved from a local worker to an entrepreneur through his efficient Iron Bar Cutting and Bending Machine. Kodimunja Praveen Kumar from Telangana established himself as an agri-machinery entrepreneur with his Mulberry Branch Cutter cum Binding Machine, creating employment in the sericulture sector.

Yet, these success stories also revealed the challenges grassroots innovators face in their journey. Participants emphasized that such transformations require systematic support-financial assistance during development, technical mentoring, internship programs for company management, and inter-innovator networking. Swapnil Jagtap stressed that early market entry and user feedback are crucial, while Ajay Kumar Prusty advocated for quality maintenance through Kanban mechanisms. These discussions underscored that with proper ecosystem support, every grassroots innovator has the potential to become a successful entrepreneur and employer.

The Road Ahead

The journey to Viksit Bharat 2047 cannot be traversed solely on the highways of high-tech industries and urban development. It requires nurturing the village paths of grassroots innovation that connect India's diverse communities to the mainstream economy. The innovations discussed at this roundtable represent just a fraction of the creative potential that exists across India. Beyond these, NIF has documented thousands of innovations addressing diverse needs-from Subhash Vasantrao Jagtap's Sandalwood Paste Making Machine that serves temples across the country, to the Areca-nut Polisher developed by Lalbiakzuala Ralte helping farmers in the Northeast, to herbal formulations for livestock health like Wormivet, Estrona, and Mastirak gel that serve India's rural animal husbandry sector.

To unlock this potential at scale, sustained institutional efforts are imperative. As NIF continues to scout, document, and support these innovations, the integration of engineering, design, and safety perspectives-as emphasized by academicians at the roundtable-becomes essential. To translate such insights into actionable policy, roundtables like this one should become a regular feature across states and districts, creating a feedback loop between grassroots innovators and policymakers that can inform and strengthen policies for effective dissemination of these innovations to every corner of the nation.

With such an ecosystem in place, the true impact of grassroots innovations can be realized. The innovations highlighted during this roundtable-from herbal toys preserving tribal heritage to solar-powered machines transforming agriculture, from automated looms liberating weavers to affordable tools empowering small farmers-are not merely products. They are reflections of Indian ingenuity, symbols of inclusive development, and building blocks of a self-reliant nation. As India aims to become a $30 trillion economy, ensuring that its benefits reach all citizens through grassroots innovations will determine whether we achieve a truly 'Viksit' (developed) Bharat or merely an economically advanced one. The silent engines of transformation are running; it is time to give them the fuel of policy support, financial backing, and the recognition they deserve. ∎

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