राष्ट्रीय नवप्रवर्तन प्रतिष्ठान – भारत
विज्ञान एवं प्रौद्योगिकी विभाग, भारत सरकार का स्वायत्तशासी संस्थान
National Innovation Foundation - India
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HERBAL PHARMACEUTICALS, STANDARDIZATION & ITS IMPLICATIONS

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Editorial

India's next phase of development will be combinedly determined by rapid adoption of frontier technologies with mainstreaming of grassroots innovation technologies and resurrection of Indian outstanding traditional knowledge systems. This is where the idea of Sapt Dhara, (the seven streams of strength) propounded by The Honorable Prime Minister, becomes particularly interesting. It includes manufacturing; agriculture and food processing; technology and innovation; Gati Shakti; defence; the green and blue economy; and soft power, as the pillars of national development. In this regard, the Grassroots innovation system offers a substantial pathway to integrate the knowledge of farmers, artisans, mechanics, workers, small entrepreneurs, and school students, to the Sapt Dhara of national capabilities. It represents a distributed source of socio-technical knowledge development. This gives grassroots innovation a distinctive economic value. It is not merely about making affordable products but also discovering problems and complement formal innovation domain.

The ambition under Sapt Dhara is not simply to manufacture more, but to develop complete value chains, improve quality and compete globally. That requires sophisticated research and industrial capability. But it also requires an enormous amount of knowledge about how products behave in actual working environments. A machine modified by a farmer, a tool redesigned by a worker or a process adapted by a grassroots entrepreneur may reveal exactly where conventional product design is failing. Grassroots innovation can therefore function as a feedback mechanism for industrial innovation. NIF's work provides many such examples. This proximity to the problem can be an important advantage when designing technologies for large and diverse markets.

Technology and innovation deserve an expanded interpretation. India is building capabilities in artificial intelligence, quantum technologies, robotics, space and advanced communications. We have to be aware that modern innovation system should not create impression of frontier science sidelining locally developed solutions as peripheral. Because both can strengthen each other. The same logic has implications for Gati Shakti, the connectivity. Connectivity is generally understood in physical terms, for example, roads, railways, ports, waterways and logistics. But connectivity in an innovation economy also means connecting ideas to institutions. An excellent local technology can remain economically invisible if the innovator cannot access testing facilities, intellectual-property support, finance, certification, manufacturing partners or markets. NIF is serving as an institutional bridge to facilitate dedicated grassroots innovators the national R&D infrastructure.

India's ability to create solutions from scarcity is itself part of its intellectual and cultural heritage. Our nation is eminently capable of producing sophisticated digital infrastructure and advanced scientific technologies while simultaneously generating ingenious low-cost solutions at the village level with a distinctive innovation identity. Therefore, the real opportunity is to make grassroots problem-solving a cross-cutting capability within all seven streams of Sapt Dhara of national development, and galvanize India's march towards the developed India.

Dr. Arvind C. Ranade

Herbal Pharmaceuticals, Standardization and its Implications

Akshay Kumar Lunawat and R K Ravikumar

Herbal medicinal products are highly valuable to health care system for human and veterinary health care system. Evolving nature of society and modern walks of life creates different health issues, necessitating need to effectively address them. Metabolic, hormonal disorders; development of antibiotic resistance and their residue are becoming a concern in health system. This led to higher demand for herbal products. Society inherently relies on herbal system as it is rooted in its tradition, culture. Systemically advancing these herbal practices into commercial ventures is pertinent as these practices are socially validated. Scientific assessment helps to validate claims, address safety and enhance rate in development of standardized products.

Herbal medicinal products have to possess consistent (uniform) biological activity for meeting requirement of bodily function. These features can be sustained by adhering to regulatory guidelines thereby safeguarding public health, trust. Herbal pharmaceuticals rely on such systemic approaches to meet product standards. This includes identification of herb, marker compounds by which quality, safety of sample is ascertained. Further, extraction procedures, drying, size reduction are important aspects in influencing efficacy of the product. Overall, these pharmaceutical manufacturers and drug regulatory agencies rely on attributes described in Good Manufacturing Practices [GMP].

Development of herbal medicinal products:

Herbs are integrated in the health care system in various regions across world. The recorded establishment of herbal medicinal garden like Hortus Medicus, Amsterdam [1639] in Netherlands; Padua Hortus Medicus [1545] in Italy illustrate exchange of herbal knowledge, their utilization in health system [Popovic and Rijker, 2025]. Theories and practice of herbal based system are referred in ayurvedic works (Charaka Samhita, 1200–500 B.C), Siddha literature (2000 BC), Unani system (Greek origin, 400 B.C.) (Ijinu et al., 2022) and Sowa-Rigpa, tibetian medicine having record of about 2,500 years old (Roberti et al., 2011). These system of knowledge illustrates continuous evolution of health care approaches based on inherent knowledge of society. Scientific evidences were documented, establishment of modern infrastructure facilities assisted in development of pharmacopoeial guidelines.

Herbs that are recognized for their functional properties require certain standardization and systemic approaches for commercial or social exploitation. These herbal formulations are generally accepted by societies due to perception on safety and cultural identity. It is also increasingly recognized by affected patients in terms of tolerability of herbal formulations. Herbal products are becoming rationale alternative to ailments, recognized by several countries as modern scientific knowledge helps in development of standardized therapies. Therefore, herbal ingredients have to adhere established guidelines so as to meet specific claim/efficacy in management of health care.

Traditional system, which are primarily plant based are highly relevant and known for their efficacy, cost effectiveness. Currently, more than 80% of the population living in over 170 of 194 member States of World Health Organization [WHO] relies on some form of traditional medicine. There is imminent necessity to explore medicinal approaches due to epidemiological nature of various ailments, which are increasingly difficult to control under prevailing therapeutic approaches. Further, herbal medicinal system is presently underrepresented in clinical therapies and advancement of herbal pharmaceutical system helps in addressing multi-morbid conditions. There are reports of treatment discontinuation due to unintended side effects and upon finding that first line of treatment did not yield desired improvement. This led to enhanced research on herbal medicine.

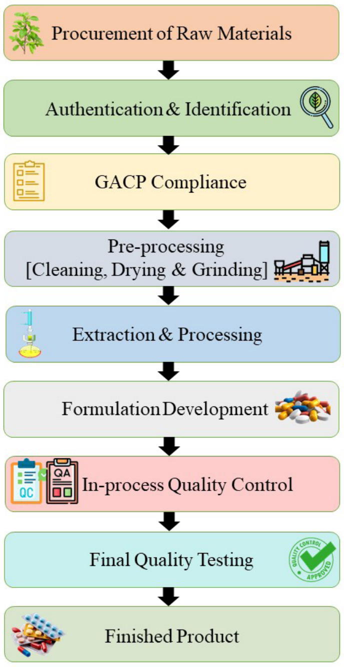
Health care professionals often prescribe multiple medications having single drug moiety to protect the biological system. This had led patients to explore multiple drugs or overlapping medications (Shin et al., 2011). Hence, demand for herbal drugs are observed in quest for therapies and to minimize polypharmacy, which are often found with patients having comorbidities. Regulatory system also examines reference of herb(s) being described in recognized pharmacopoeia. As such reference indicates herbal standardization in terms of safety, usage pattern and therapeutic efficacy of herbs, their information being held over period. This facilitates progress in drug development efforts and as a valuable source of evidence. These herbal drugs, supplements augment well in optimization of medications which are critical among oWWlder patients and individuals affected with multiple illness. Such an approach reduce rate of hospital admission, aids patients approach for effective non-prescription [NP] drugs and lessen burden on health care professionals. On several occasions, patients rely heavily on para-health care professionals both in human health and veterinary system(s). This obliges herbal drug manufacturers to adhere to regulatory standard for ensuing quality of products. Each of these plant based herbal formulations are based on either single or multiple herbs, comprises of variety of phytochemicals. These are secondary metabolites of herb, offer functional properties in health care. The phytochemical profile is most valuable tool in development of herbal products. Clinical translation of these formulations depends on bioavailability of these compounds. Hence it is appropriate at initial level to understand the principal phytochemical(s). There are occasions that specific or active ingredients contributing to the functional property is unknown in these herbal products. In such scenario, chemical profiling of the product is necessary. These are referred as marker compounds, which may or may not contribute to efficacy, but pertinent for quality control measures of herbal medicine. They help to identify and to assess their quantity in herbal medicinal products.

Herbal pharmaceuticals and Quality standards

Herbal medicinal product development involves understanding of phytochemistry and formulation development process apart from establishment of safety, efficacy, pharmacognosy studies. Development of quality parameters helps to have batch-to-batch uniformity, adhere to regulatory compliance thereby promotion of global acceptance of herbal medicines. Accordingly, WHO indicated to have an uniform guideline for herbal pharmaceutical products and such guideline was adopted in the year 2006 [WHO Technical Report Series, No. 937, 2006]. This WHO-Good Manufacturing Practices [GMP] had provided necessary measure to adopt and led national agencies to regulate their herbal manufacturing system. Such certification process authenticate consistent and quality production, documentation of proper batch record.

These guidelines emphasize botanical authentication and chemical profiling as crucial in transforming inconsistent traditional remedies into reproducible therapeutic agents. Such standardization is validated through application of chemical markers. These specific molecules/bioactive chemical assist in identifying consistent profile of herbal products. These phytochemicals serve as a plant's unique signature. Manufacturers identify these chemical fingerprints, ensure each of the batch contains precise concentration of active ingredients that are required for predictable clinical outcomes. WHO-GMP ensures minimizing variability by enforcing process validation, SOPs, sanitation controls, and documentation systems so that each batch produced is consistent in quality these are assessed by independent Quality Control [QC] and Quality Assurance [QA] units along with validation of equipment and their processes, environmental monitoring. WHO-GMP certification is a critical tool for international trade and operational sustainability, as many countries require this certification as a prerequisite for the import and export of medicines, making it essential for global market access [Wang et al., 2023].

Pharmaceutical manufacturers must obtain regulatory approvals and licenses under the Drugs and Cosmetics Rules, 1945 before market release. This act provide a legal framework for Ayurvedic, Siddha, and Unani [ASU] systems by governing manufacturer. The key provision include Schedule T, which is related to infrastructure, sanitation, equipment, qualified technical staff, documentation, and quality control systems, Schedule U, related to batch manufacturing records to ensure traceability and accountability and Schedule E [1] which identifies potentially toxic substances that must undergo proper purification before use. Their facilities are subject to periodic inspections for continued compliance with GMP standards. Analytical standardization also requires careful selection of methods according to the characteristics of the herbal material and the purpose of testing. A single marker may be useful for identity or routine quality control, while a broader chemical profile may be required when several constituents contribute to product characteristics. The objective is to generate a reproducible quality profile that can be compared across batches while recognizing the inherent complexity of plant-derived materials. It is to be observed that, standardization is not limited to testing the final formulation, it represents a continuity of quality control extending from selection of raw materials (botanical source) to release of finished product. A reliable standardization strategy have to organize on botanical identity, processing conditions, phytochemical profile and defined quality attributes. Such an integrated approach is important for formulations containing multiple herbs, wherein variation in the proportion or quality



Flowchart

of individual ingredients may influence overall chemical profile. Establishing reference points at each stage can make the manufacturing process more reproducible, can strengthen assurance for the intended therapeutic use.

Herbal formulations, throughout the product lifecycle, have to meet consistency, safety and reproducibility of efficacy at every stage of production is vital [Gorukanti et al., 2025]. Stability studies like long term, accelerated, intermediate forms assist in such process and to comply with International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use - ICH Q1A(R2). These are conducted to determine shelf life and storage conditions, ensuring that the product remains safe and effective throughout its intended use period, even under varying environmental conditions. In manufacturing of herbal products, a structured pathway in tune with regulatory, quality assurance requirements/ principles are conducted. This include authentication of raw material, procurement supported by Good Agricultural and Collection Practices [GACP]. Sourcing of raw materials involve macroscopic, microscopic, and phytochemical identification. These conferment helps to lessen variability and preserve therapeutic constituents. This is followed by pre-processing steps such as removal of foreign matter, drying under controlled environment (Temperature, humidity) so as to prevent degradation of principle or active organic compounds, achieving uniformity by size reduction either through grinding or pulverization as well as extraction efficiency. In processing and formulation steps, dosage form is standardized through validated techniques like decoction, infusion, distillation, or solvent extraction. This will assist in development of various dosage forms such as powders, tablets, syrups, oils, or extracts. The critical parameters in this stage include temperature, pressure, duration of extraction and solvent ratio. This will determine the reproducibility of efficacy of the product, carefully maintained, documented. These critical quality attributes [CQA] are valuable tools.Parameters like moisture, pH, uniformity and yield are monitored at multiple stages as a part of quality control as each intermediate product have to meet predefined specifications in ascertaining consistency. The finished product is analysed interms of physicochemicals, chromatographic profiling, microbial load, presence of heavy metal, pesticide residue and stability studies. This will help to comply with established guideline such as WHO-GMP certification so as to confirm with safety, efficacy and batch-to-batch consistency. Chemical markers have to be part of guidance for QC and QA for broad application, their bioavailability and synergistic properties. Labelling is done in accordance with regulatory requirements, ensuring inclusion of essential information viz, ingredients, dosage, indications, batch number, manufacturing license number and expiry date. These will help towards traceability and for safe usage of herbal drugs.

Various cultural system had nurtured herbal traditions and helped in evolution of medicinal system. Indigenous or folkloric system offer insights and incorporating them help in medicinal knowledge, public health. These herbs or ethnobotanicals have multiple characteristics that include nature of cultivation, different forms of preparations as well as to meet various regulatory requirements. Laboratories used to have analytical issues to appreciate quality, safety and standardization parameters. There is pressing need to detect contamination and adulteration. These exercises have to be carefully considered as many phytochemicals are not listed in scientific database or readily available. Standardization of herbal medicinal products require certain approaches in terms of establishing suitable reference points. They have to be part of critical quality attributes to meet demand of industry. Appropriate selection of analytical tool helps to study herbal medicinal products and to meet the desired objectives. In herbal medicinal context, pharmacopoeias provide requisite guidelines for regulatory authorities. Efforts have to be made towards incorporation of herbs which are not listed in recognized pharmacopoeias to sustain, scale-up. The interface of established herbal medicinal system with modern technique facilitate in development of standardized herbal therapies both for veterinary and human health.

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Innovator of the Month: Jaswinder Singh

Jaswinder Singh from Malerkotla, Punjab runs a small mechanical workshop where he designs and fabricates machines according to the needs of farmers. He has a long experience in the field of machine manufacturing. He lives with his wife and a son. His son Pavneet Singh also helps him in his workshop. In 2014, a farmer came up to him with the problem of preparing a nursery with the help of a single machine. He took interest in the problem and decided to work on it and eventually succeed in making the machine.

Tractor-operated multi-crop seed sowing machine developed for efficient and precise seed sowing for nursery raising.

Traditionally, nursery preparation required several labourers and involved separate machines for bed preparation, furrow making and seed sowing. This made the whole process time-consuming and increased the overall cost of operations. To address these challenges, he designed a machine that integrates all three operations into a single operation. This machine also decreases the labour cost and the cost occurs in procuring multiple machines for the operations.

Jaswinder Singh
Innovator
Malerkotla, Punjab

Jaswinder Singh has developed Tractor operated multi-sowing machine specially designed for raising nursery plants of crops such as onions, chili, cabbage, tomato etc. wwwThis machine performs three key operations: bed preparation, furrow making and seed sowing in one go. He has developed three variants: tractor-operated, pneumatically operated and manually operated. The first two variants are major selling machines. These machines required an agricultural field that was properly ploughed for nursery-making operations.

The machines are ergonomically designed and the working mechanism of this machine is very simple; once the ploughing operation is done in the field, this multi-sowing machine prepares the nursery. In the tractor-mounted multi-sowing machine, as the tractor moves forward at a specific speed, this machine prepares the bed and furrow and simultaneously sows seeds in the furrow following a particular pattern. The innovator developed a unique seed metering system for seed sowing operation. Moreover,

Pneumatic multi-crop seed sowing machine developed by Jaswinder Singh and field demonstrations conducted by the NIF team, for evaluating its precision and efficiency in nursery bed preparation and seed sowing.

the machine is compact, ensures accurate and uniform seed sowing. It is suitable for nursery preparation for both small and large agricultural fields.

Pneumatic multi crop sowing machine is an advanced version developed by Singh. The engine generates power to drive a belt and pulley system, which operates a blower. The blower generates a vacuum within the hollow cylindrical pipe, which functions as a seed metering system and effectively controls the flow of seeds. As the hollow cylinder rotates, it picks up seeds through multiple holes, which are released precisely into the soil after striking the rubber plate. The machine is equipped with two power sources: one for the forward movement of the machine and the other for generating the vacuum required for seed sowing. This dual functionality enhances the efficiency and precision of the sowing process, while ensuring effective seed placement and smooth machine movement. The machine is manually operated by a single person. The machine can sow 19 seeds in a single row over a total length of 3 feet, resulting in a seed-to-seed distance of 1.89 inches. This spacing is ideal for nursery preparation. The machine can cover 0.05 hectare per hour, with a field efficiency of 85% and reduces seed wastage by 40–50%. In 2023, Singh, who was running a small workshop, came into contact with National Innovation Foundation-India. NIF has supported the innovator through various stages, including value addition, product development, IPR filing, commercialization. He has established a small venture, JS Fabricators and Agro Machinery Manufacturers, a proprietorship firm to manufacture and sell agricultural machinery. A patent application has also been applied for his innovation.

Singh's journey as a grassroots innovator also inspired his son, Pavneet Singh, to develop solutions for the challenges faced by the small & marginal farmers. He has developed Tractor Mounted Hydraulic Weeder designed for delicate floriculture crops, enabling precise dual weeding. It minimizes the damages occur during weeding to the main crop. The innovative machine can cover 2 acres per hour, thereby reducing dependence on the manual labor. Its adjustable spacing also provides flexibility, making it suitable for a wide variety of floriculture crops.

Presently Singh has successfully sold 100+ machines across Punjab and has been recognized with the Grassroots Innovator of Punjab (GRIP 2.0) award. His son Pavneet Singh has also received Grassroots Innovator of Punjab (GRIP 4.0) award. The true success of an innovation lies not only in the quantifying impact it creates, but also the inspiration it leaves behind. When the spirit of innovation passes from one generation to the next, it keeps creativity, curiosity and problem-solving alive. Singh's journey is the example of this legacy, as he motivated his son to address the social challenges faced by people around him. Such continuity demonstrates how one innovator's work can inspire the next generation and in turn, encourage others to develop sustainable solutions to local challenges and create a wider social impact.

When honeybees met Sitara Sringar mustard: A synergistic relationship for sustainable agriculture

Moumita Sahoo, Hardev Choudhary, and Vivek Kumar

In the villages of Kendrapara district of Odisha, mustard cultivation is a familiar part of the winter agricultural landscape. Equally familiar, though often treated as a separate enterprise, is beekeeping. A recent pilot field study conducted by us has demonstrated that when these two activities are brought together in a carefully managed system, they can create a powerful ecological partnership capable of enhancing crop productivity, improving oil recovery, strengthening pollinator populations, and generating additional income through honey production.

The idea for the pilot trial emerged from an initial field observation (shared by the farmer- Shri. Pramod Biswal) during the mustard field trial conducted throughout Kendrapara district of Odisha. A mustard field cultivated with the Sitara Sringar variety (developed by Shri Hukam Singh Lodha, Bharatpur, Rajasthan) and maintained alongside apiculture boxes unexpectedly produced unusually high quantity and quality of honey compared with the local varieties of mustard cultivated traditionally in the area. He also noticed unusually high levels of honey bee activity in fields located near managed apiaries. The flowering crop appeared to attract large numbers of foraging bees throughout the blooming period. At the same time, these fields showed excellent pod formation, better seed filling, and vigorous crop growth.

The Sitara Sringar variety is high yielding (30-35 q/ha) and has good oil content. It is also reported to show tolerance to pod shattering, water logging, and Alternaria leaf blight. The variety has been validated at Rajasthan Agriculture Research Institute Durgapura, Jaipur, Rajasthan. Furthermore, the variety is registered under PPV&FR Act, 2001. Shri. Lodha has received several recognitions and awards, including the National first award from NIF-India during the 8th National Grassroots Innovation Festival-2015 (i.e., 8th Biennial awards in 2015).

What initially appeared to be a fortunate coincidence during the on-field trial soon attracted attention because the benefits were being observed simultaneously in both the crop and the bee colonies. This unusual interaction between honey bees and Sitara Sringar mustard inspired a more structured on-field investigation in the following season. Three mustard fields (belonging to Shri. Rajdeep Bal, Shri. Amar Ku. Parida, and Shri. Khirod Ch. Swain) were therefore selected in Kendrapara district for a pilot trial integrating managed apiculture boxes with the Sitara Sringar mustard variety.

The findings were remarkable. One of the most significant observations was the influence of

Farmer handling bee box.

Sitara Sringar mustard in field with bee boxes.

Data collection in Sitara Sringar mustard field with bee boxes.

bee-assisted pollination on crop maturity. Farmers cultivating Sitara Sringar under conventional conditions generally expected the crop to mature in approximately 130 days. However, in fields integrated with managed bee colonies, maturity was achieved in nearly 90 days. This reduction of around forty days was unexpected and immediately drew attention because of its practical implications.

For farmers, earlier maturity means more than an earlier harvest. It reduces the crop's exposure to terminal heat stress, protects it from late-season climatic uncertainties, and creates opportunities for timely planting of subsequent crops. In regions increasingly affected by weather variability, shorter crop duration can contribute significantly to climate resilience and improved cropping intensity. What farmers observed in their fields aligned with scientific evidence suggesting that effective pollination can accelerate reproductive processes, leading to earlier completion of flowering and seed development.

The impact of honey bee activity was equally visible in crop productivity. Mustard is a partially self-pollinated crop, but its reproductive performance improves substantially when pollinating insects facilitate cross-pollination. Throughout the flowering season, honey bees moved actively across the crop canopy, transferring pollen between flowers while collecting nectar and pollen.

Farmers observed healthier silique development and more uniform seed filling across plants. Detailed field observations revealed plants carrying abundant pods, often ranging from 100 to 150 silique per plant, with 20 to 30 seeds per pod. The resulting harvests were noticeably higher than those typically obtained from comparable fields lacking managed pollination support. Enhanced fertilization appeared to reduce flower and pod abortion while improving the conversion of flowers into fully developed seed-bearing pods. The result was a more productive crop with better overall performance.

One of the most remarkable outcomes of the pilot study was the exceptionally high oil recovery observed in the Sitara Sringar variety. While conventional mustard varieties typically required approximately 5 kg seed to produce 1 liter of oil (around 20% oil content), only 2.8–3.0 kg seed was needed in the present trial, corresponding to an estimated oil content of nearly 38%. For participating farmers, this translated into a tangible increase in value from the harvested crop. The higher oil recovery not only enhanced the market potential of the produce but also strengthened confidence in the variety itself. Therefore, we believe that the combination of efficient pollination and the inherent genetic characteristics of Sitara Sringar contributed to this outcome. Better pollination typically leads to more complete seed development and greater accumulation of storage compounds, including lipids, thereby improving oil recovery.

While the crop was clearly benefiting from the presence of honey bees, the bees themselves were deriving equally important advantages from the Sitara Sringar mustard ecosystem.

Throughout the flowering period, the Sitara Sringar crop provided abundant nectar and pollen resources. For honey bee colonies, pollen serves as the primary source of protein and is essential for brood development, worker longevity, immune function, and colony growth. Farmers involved in the study observed strong foraging activity from sunrise to sunset, with bees actively visiting flowers across the fields.

The availability of abundant floral resources appeared to support colony expansion and improve overall colony strength. Brood development was more vigorous, food reserves increased steadily, and colonies maintained high levels of activity throughout the flowering season. The continuous supply of nectar and pollen helped sustain healthy colony populations during a critical period of development.

Discussion with farmer on field having local mustard variety

These improvements in colony performance were reflected in honey production. Beekeepers reported higher honey yields than normally obtained during the mustard flowering season. The honey produced near Sitara Sringar fields also exhibited desirable characteristics related to texture, consistency, and overall quality. The observations suggest that the floral characteristics of the variety may provide particularly favorable conditions for nectar collection and honey synthesis.

For farmers who combined cultivation of Sitara Sringar mustard with apiculture, this created a dual-benefit system. The crop benefited from enhanced pollination, while the bee colonies benefited from an abundant and nutritious forage source. Together, these interactions generated value from two distinct agricultural enterprises operating within the same landscape.

An additional feature that attracted considerable interest among participating farmers was the non-GMO status of Sitara Sringar. In recent years, discussions surrounding genetically modified mustard have generated considerable debate regarding long-term ecological and environmental implications. Farmers involved in the pilot study appreciated that the variety demonstrated high productivity, strong pollinator compatibility, improved oil recovery, and enhanced honey production without relying on genetic modification technologies.

The Kendrapara (Odisha) pilot study demonstrated that pollination should not be regarded merely as an ecological service occurring in the background. Instead, it can function as a productive agricultural input capable of improving yield, quality, and resource-use efficiency. Mustard honey is widely valued for its important nutritional and medicinal properties. It is typically light yellow to golden in color and contains a rich combination of natural sugars, amino acids, enzymes, vitamins, minerals, organic acids, and bioactive phytochemicals that contribute to its therapeutic potential. In addition, mustard honey contains antioxidants such as phenolic compounds and flavonoids that help reduce oxidative stress and protect cells from free radical damage. Traditionally, mustard honey has been used in folk medicine for relief from cough, cold, sore throat, digestive disorders, and wound healing because of its antimicrobial and anti-inflammatory properties. Furthermore, the floral diversity (in this case Sitara Sringar flowers) can influence the biochemical richness, antioxidant activity, and sensory characteristics of honey, thereby enhancing its medicinal value. Due to its natural nutritional composition and therapeutic significance, mustard honey is increasingly recognized as a functional food with potential applications in health promotion and nutraceutical industries.

For the participating farmers, the integration of bee boxes into mustard fields required only modest adjustments to existing practices.

Harvested seeds of Sitara Sringar.

However, the resulting improvements in crop performance and honey production suggested that relatively small interventions can generate substantial returns when ecological processes are effectively harnessed.

Although the findings are highly encouraging, we emphasize that this was a pilot-scale investigation. Further, multi-location studies across different agro-climatic regions have to be conducted in order to validate the consistency of the observed outcomes. Future research will need to examine pollinator dynamics, oil quality parameters, honey composition, biodiversity impacts, and long-term economic viability under diverse farming conditions.

Nevertheless, the pilot study has provided valuable evidence of a promising agricultural model. It demonstrated that crop production and apiculture need not operate as separate enterprises. When integrated thoughtfully, they can reinforce one another and create a production system that is both economically rewarding and environmentally sustainable. For the farmers of Kendrapara, the experience with Sitara Sringar mustard and managed honey bee colonies offered more than an increase in yield or honey production. It provided a practical demonstration of how biodiversity-based approaches can strengthen agricultural resilience and productivity. As agriculture faces the dual challenge of meeting growing food demands while adapting to climate change, such integrated systems may offer an important pathway forward.

The partnership between Sitara Sringar mustard and honey bees transformed an ordinary mustard field into a living example of ecological synergy—one that has the potential to contribute meaningfully to sustainable agriculture, pollinator conservation, and rural prosperity in the years ahead.

Acknowledgement:

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Sitara Sringar mustard in field without bee boxes.

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Training Programs on Grassroots Innovation and Value Addition at BUAT, Banda

Navneet Kumar and Nitin Maurya

Agriculture is undergoing a quiet change in Bundelkhand, where age-old farming challenges are now being addressed through modern technologies based on grassroots ingenuity. In an effort to boost local livelihoods, rural entrepreneurship, and farm-level value addition, National Innovation Foundation – India (NIF) organised a series of hands-on training programs on grassroots innovations with/at the Banda University of Agriculture and Technology, (BUAT) where its Krishi Vigyan Kendras (KVKs) also participated. The multi-day activity showcased grassroots innovations from across India, drawing enthusiastic participation from university staff, Farmer Producer Organizations (FPOs), and Self-Help Groups (SHGs) hailing from the Banda and Chitrakoot districts.

One of the major hurdles faced by farmers in Banda and Chitrakoot districts has always been post-harvest losses and distress selling during market oversupply. The recent training camp directly addressed this through live demonstrations of affordable, farmer-friendly machinery. The training schedule included functional low-cost machinery designed to enhance rural income generation, promote waste-to-wealth models, and foster sustainable practices.

From Field to Market: Transforming Produce into Profit through Processing

Multipurpose Food Processing (July 20–21, 2026): Prince, son of innovator Dharambir Kamboj, from Yamunanagar, Haryana, led the training on multipurpose processing machine. The participants learned to operate and manage the machine that processes fruits without the damaging seeds, extracts essential oils, and which can be used to produce dozens of products. Trainees successfully produced mango and orange juices, fruit squashes, tomato sauce, purees, chili sauce, papaya jam, alongside wellness items like aloe vera gel, shampoo, and natural essences.

Participants learn hands-on techniques for producing sustainable cow-dung products, including eco-friendly pots, burning logs, and traditional utility items, using specialised equipment.

Vegetable Deseeding (July 22, 2026): Dilip Kumar Baral from Puri, Odisha, demonstrated his unique deseeding machine. The machine enables farmers to cleanly extract seeds from surplus vegetables like tomatoes and and brinjals during periods of produce oversupply, turning potential crop loss into a profitable alternate income stream.

Participants observe an innovative vegetable-deseeding machine designed to efficiently extract seeds from surplus vegetables, creating an additional value stream for farmers.

Mini Dal Milling & Organic Composting (July 23–24, 2026): Innovator Bharat Chandra Rout


Participants observe improved mini dal milling and learn techniques for processing pulses and converting biodegradable waste into high-quality organic compost.


Participants receive hands-on training to make sustainable alternatives to plastic and firewood, including cow-dung pots, burning logs, and traditional utility items, using specialised presses under expert guidance.

from Odisha showcased the Improved Mini Dal Mill, training rural entrepreneurs on processing pulses like pigeon peas, lentils, black grams, and soybeans for in-situ farm-level value addition. The other session by Bharat Chandra Rout focused on converting biodegradable waste—such as cow dung and kitchen scraps—into high-grade granular organic compost using his specialized composting unit.

Eco-Friendly Cow Dung Products (July 25, 2026 & June 20–23, 2026): Guided online by Devang Khambhayta (Ahmedabad, Gujarat) and in-person by Arvindbhai Kiyada (Rajkot, Gujarat), the participants received training in crafting sustainable alternatives to plastic and firewood. Trainees manufactured eco-friendly cow dung pots, burning logs, and traditional utility items using specialized presses.

The success of these extensive training sessions was made possible by the unwavering support of the BUAT officials. The event concluded with high enthusiasm among the local farmers and women from SHGs and FPOs, who acquired hands-on expertise on grassroots technologies aimed at increasing rural incomes and promoting sustainable self-reliance across the Bundelkhand region. These workshops were more than just training sessions; they were the first steps of NIF's initiation in the region in partnership with the BUAT and stepping stones towards helping farmers and rural communities achieve self-reliance, higher incomes, and sustainable rural futures.

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Roots of Change: How Grassroots Innovators are Growing Sustainable Farms

Rakesh Maheshwari

Walk into any village in India, and you will meet a farmer, a mechanic, or a young student who has built something clever out of scrap parts and hard-won experience. These are not scientists in big laboratories. They are grassroots innovators. Their machines are small, cheap, and built for real problems. Together, they are quietly changing the shape of Indian farming, and making it more sustainable in the process.

Sustainable farming means using less water, less fuel, and less labour, while growing more food and protecting the soil. It also means giving farmers, especially small and marginal ones, a fair chance to earn a living. In India, small and marginal farmers make up over 85% of the farming population, but they work on less than half of the farmland (Down to Earth, 2025). Their margins are thin. A costly tractor or an imported machine is often out of reach. This is exactly the gap that grassroots innovation fills. Here are a dozen such innovations, documented by the National Innovation Foundation – India (NIF), that are quietly making farms more sustainable.

Tilling, Sowing and Weeding, Without the High Price Tag

Mr. Rajendra Lohar, a mechanic from Jalgaon, Maharashtra, built a multipurpose power tiller. It can plough, sow seeds, spray, and weed, all with different attachments. Mr. Kadivendi Mahipalchary, a mechanic from Warangal, Andhra Pradesh also built a multipurpose power tiller. It can do shallow ploughing and do intercultural operations (hoeing and weeding). Machine developed by both of them run on a small 5 hp and cost about Rs. 45,000 and can plough in 0.5 acre/h. For a farmer with just one or two acres, these machine can mean the difference between farming being profitable or not.

Similarly, the sugarcane bud chipper made by Shri Roshan Lal Vishwakarma of Narsinghpur, Madhya Pradesh, removes buds from sugarcane stalks for planting. It has helped farmers save over 80% of the cost of plantation. That is a large saving, achieved with a simple hand-pressed tool.

Weeding is one of the most tiring jobs on a farm. It is done by hand, bent over, for hours. In Mahabubabad, Telangana, mechanic Repalle Shanmukh Rao designed a battery-operated power weeder that runs on solar or AC charging, and needs only 7 hours to weed 2 acres.

Battery operated weeder by Repalle Shanmukh Rao, Mahabubabad, Telangana.

Multipurpose power tiller by i) Rajendra Lohar, Jalgaon, Maharashtra and ii) Mr. Kadivendi Mahipalchary, Warangal, Andhra Pradesh

Sugarcane bud chipper by Roshan Lal Vishwakarma, Narsinghpur, Madhya Pradesh.

Similarly Injapuri Anjaiah of Jagityal, Telangana developed a weeder powered by a DC motor with a simplified design. Based on farmers' suggestions, a solar panel was added to ensure continuous weeding without interruptions. Four hours of charging can cover acre of field.

Single wheel solar powered weeder by Injapuri Anjaiah , Jagityal, Telangana

Working Safely, Even High Up in the Trees

Not all farm work happens on the ground. Coconut, areca, and palmyra growers must climb tall trees for harvesting, often without any safety gear. This has long caused injuries and deaths. Mr. D. N. Venkat of Coimbatore, Tamil Nadu, designed the Multi Tree

Multi Tree Climber by D. N. Venkat, Coimbatore, Tamil Nadu, in use on a coconut tree.

Climber, a manually operated harness-and-ladder device with a seat and a locking system, that lets a worker climb to any height safely. He has sold thousands of units in India and abroad, and the device has measurably reduced climbing accidents. This is important to keep in mind that sustainable farming is not only about crops and soil. It is also about protecting the people who do the hardest physical work.

Saving Water, the Most Precious Input

A rain water syringe for recharging groundwater, developed by Mr K J Anto-ji, Cochin , Kerala

Solar-powered Natural Water Cooler by Arvindbhai Patel, Ahmedabad, Gujarat.

Water is the biggest worry for Indian farmers. Innovators have found simple ways to save it. Shri K J Antoji of Cochin, Kerala, developed a Rain Water Syringe that injects rooftop rainwater deep into the ground through a narrow borehole. It needs only a one-foot-wide hole, compared to the usual 2.5 feet, and can recharge deep aquifers. Over 200 of these systems are already working along the coast of Kerala.

At the other end of the farm, the Natural Water Cooler by Shri Arvindbhai Patel of Ahmedabad, Gujarat, cools drinking water using a moist cloth and a small solar fan, with no electricity bill and no chemical cooling gas. It cools water by up to 9 degrees Celsius, with close to 90% efficiency, and over 620 units have been sold.

Cooking and Processing with Less Fuel

A large amount of fuel is burnt every day in rural India, for cooking, for boiling milk, and for processing crops. Mr. V. Jayaprakash of Calicut, Kerala,

Improved wood stove with a secondary burning chamber by V. Jayaprakash, Calicut, Kerala.

added a secondary burning chamber to a simple wood stove, so that unburnt smoke is burnt a second time. Tests by IIT Guwahati and TERI University confirmed the stove is about 30% more fuel-efficient, and it releases far less smoke, protecting the health of women who cook on it every day. Thousands of these stoves have been sold.

On a larger scale, Shri Subhash Ola's Modified Boiler, used in food processing units such as jaggery and mawa making, recycles used steam instead of losing it. This single change cuts fuel use by up to 30% and water use by up to 80%. And Mr. Rai Singh Dahiya of Jaipur, Rajasthan, has built a Biomass Gasification System that turns dry wood, coconut shells, and farm waste into a clean-burning gas, which can run generators of 5 to 100 kVA. This gives farms and small industries a way to make their own power

Modified boiler with steam-recycling, installed at a food processing unit by Subhash Ola, Alwar, Rajasthan.

Trailer-mounted Biomass Gasification System by Rai Singh Dahiya, Jaipur, Rajasthan.

from waste, instead of relying only on diesel.

Turning Farm Waste into Wealth

Sustainable farming is also about what happens after the harvest. The Tractor Mounted Rapid Compost Maker, built by Shri Gurmail Singh Dhonsi of Sriganganagar, Rajasthan, turns farm waste into manure in 25 to 40 days, instead of the usual 90 to 120 days. Tests show this compost has more nutrients, nitrogen, phosphorus, and potassium, than both regular farmyard manure and vermicompost. Faster, richer compost means healthier soil and less need for chemical fertiliser.

Tractor Mounted Rapid Compost Maker by Gurmail Singh Dhonsi, Sriganga-nagar, Rajasthan.

Leftover paddy straw is usually burnt in the field, adding to air pollution. Shri Ajay Kumar Prusty of Dhenkanal, Odisha, built a motorised Paddy Straw Cutter that chops straw bundles to the right size for mushroom beds, at a rate

Paddy straw cutter for mushroom cul-tivation by Ajay Kumar Prusty, Dhenk-anal, Odisha.

of 400 bundles an hour. Instead of going up in smoke, the straw becomes the growing medium for a new mushroom-farming income, and the innovator has already sold thousands of units.

In forest and tribal belts, Shri Jogendra Patra of Mayurbhanj, Odisha, built a machine that presses fallen Sal and Siali leaves into plates and bowls, a biodegradable, non-toxic alternative to plastic. It can make 1,000 plates or 1,250 bowls an hour, and has created employment for over two thousand people in tribal areas, turning forest litter into a livelihood.

Sal leaf plate and bowl making machine by Jogendra Patra, Mayurbhanj, Odisha.

Adding Value to the Harvest

A farmer who can process, not just grow, a crop earns more from it. Mr Dharambir Kamboj of Yamuna Nagar, Haryana, built a Portable Multipurpose Food Processing Machine that extracts juice and pulp from aloe vera, amla, jamun, mango, tomato, and other produce, without breaking the seed. More than 2000 machines have been sold within and outside India, and NIF estimates the innovation has generated direct and indirect employment for around 20,000 people. This kind of on-farm processing lets a farmer sell juice or pulp instead of raw fruit, capturing more of the final price.

Portable Multipurpose Food Processing Machine by Dharambir Kamboj, Yamuna Nagar, Haryana.

Conclusion

Research backs up what these innovators already know from experience. A study in the journal Sustainability found that small, community-level steps, better local markets, and local produce chains, make traditional farming more resilient and profitable, especially in hill and rainfed regions of India (Bisht et al., 2020). The World Economic Forum has estimated that better technology and market linkages could add about $76 billion a year of value to India's farm ecosystem, most of which would go directly to farmers (World Economic Forum, 2021).

Grassroots innovation has one more strength: it grows where formal research often cannot reach. It comes from people who face the problem every day, in the field, in the workshop, or on the roadside. NIF-India's role is to scout these ideas, test them, refine them at its Fab Lab, and help innovators reach more farmers through patents and licensing.

As one report on India's innovation ecosystem noted, local grassroots innovations happening in farming can often be scaled up, and strong links between research institutions, industry, and grassroots innovators are the key to doing this well (Kumar, 2020). The machines featured here, from a Rs. 1,800 weeder to a tree-climbing harness to a food-processing unit, are proof that this is already happening, one workshop, one field, and one farmer at a time.

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Agriculture 4.0: The Convergence of Artificial Intelligence and Grassroots Innovation for Sustainable Farming

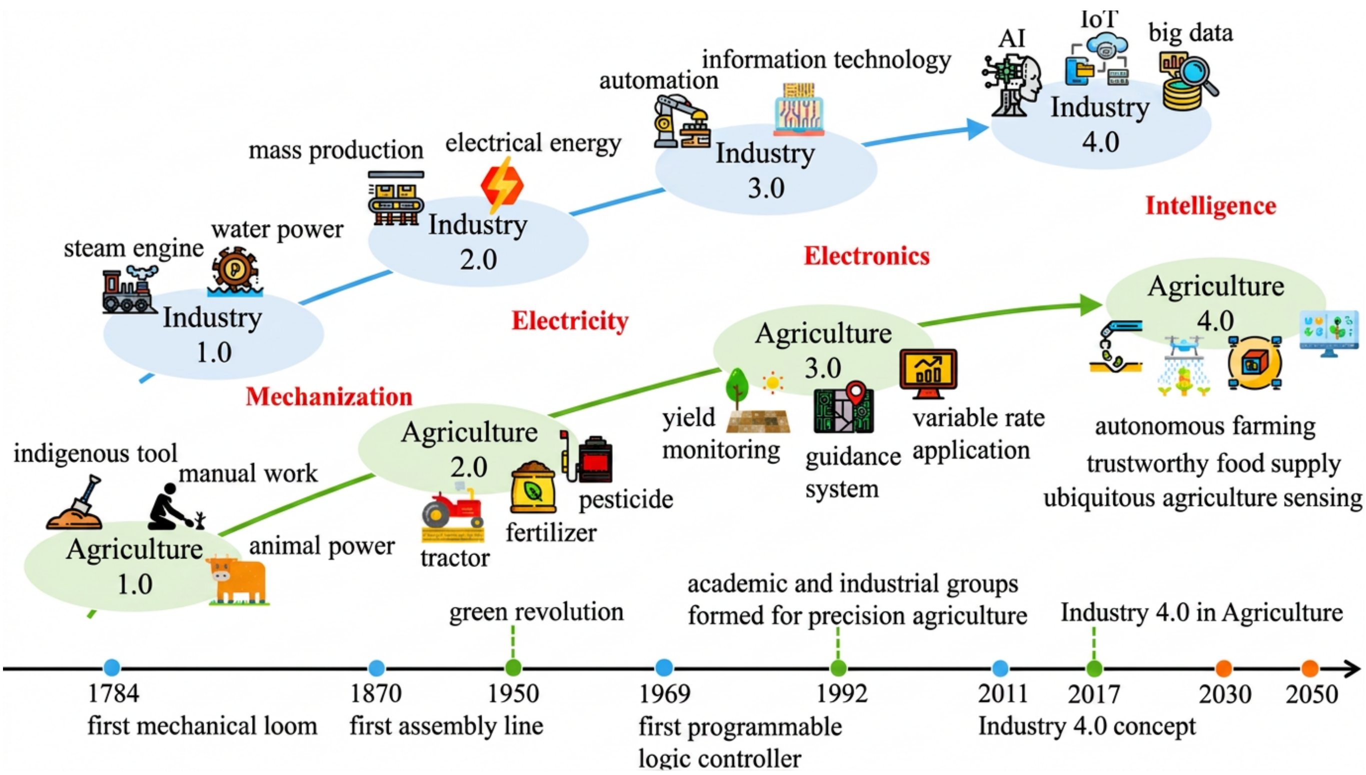
Anant Gupta

The rapid advancement of Artificial Intelligence (AI) and Industry 4.0 technologies has accelerated the transformation of the agricultural sector. Emerging technologies—including data-driven farming, vertical and urban farming, the Internet of Things (IoT), genetic modification, cultured meat, hydroponics, and precision farming techniques—are integral to the "Agriculture 4.0" movement.

However, top-down implementation often overlooks the significance of grassroots innovation. The primary contributors of frugal, localized agricultural solutions are smallholder farmers and rural communities. This article explores a sustainable farming ecosystem at the intersection of AI and grassroots innovation. By integrating advanced computational tools with indigenous knowledge, we can empower farmers, optimize resources, and ensure food security in India.

Farming in India: Crisis and Opportunity

Agriculture is the backbone of the Indian economy. However, the sector is currently threatened by climate change, soil degradation, water scarcity, and a shrinking labor force. A World Economic



Roadmap of industrial revolutions and agricultural revolutions [5]

Forum report (August 2024) indicates that 52% of Indian farmers are in debt, while 30% of India's land is degraded. Furthermore, it is projected that crop yields may decrease by 10% to 40% by 2080 due to climate change. An increasing population continues to strain traditional farming methods, making it harder to meet demand. While smallholder farmers and rural communities actively develop frugal solutions for local problems, they often struggle to scale these innovations or achieve the technological precision required to meet modern standards.

Artificial Intelligence (AI) can bridge the gap between Agriculture 4.0 and Industry 4.0. By introducing AI-driven predictive analytics, IoT sensors, and robotics into both large commercial farms and smallholdings, we can create a more inclusive technological landscape.

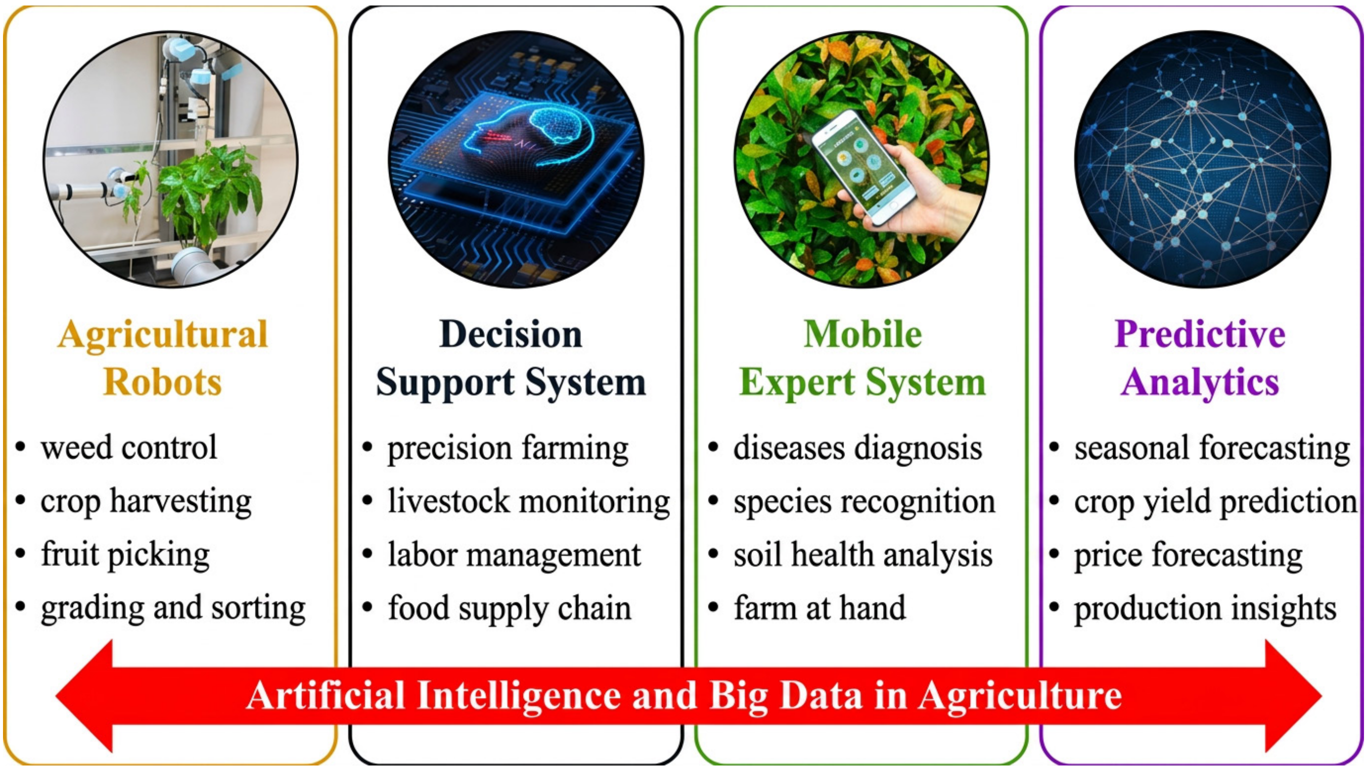
Agriculture 4.0 and Artificial Intelligence: Data-Driven Implementation

Every year, pests wipe out nearly 40% of the world's crops — worth $220 billion. In 2015, India alone lost $36 billion to pest damage. Artificial Intelligence has recently revolutionized agriculture, offering the capacity to process massive volumes of complex data. This advancement enhances pest control strategies and enables precise, localized interventions. Farming is transitioning from intuition-based practices toward data-driven prediction and planning. AI enables the seamless integration of automated machinery with digital resources, such as cloud computing and simulations.

The primary applications of AI in Agriculture 4.0 include:

a. **Predictive Analytics:** AI tools derive accurate results from weather patterns, satellite imagery, and historical data. These predictions allow farmers to optimize strategies, including the optimal timing for sowing and harvesting.

b. **Precision Application:** AI-vision-assisted drones enable the targeted application of water, fertilizers, and pesticides. This reduces manual labour in remote areas and significantly lowers operational costs.



Key applications of AI in agricultural industry [5]

c. **Field Management:** IoT-based sensors collect real-time data on soil moisture, temperature, and water levels. These sensors allow for automated irrigation systems that respond to real-time environmental conditions.

Grassroots Innovation: The Foundation of Localized Farming

In India, 85% of the 150 million farmers are smallholders, cultivating land that averages just 1.08 hectares, or 2.67 acres. Smallholder farmers often operate with limited resources and financial constraints while facing the direct impacts of climate change. To survive, these farmers continuously experiment with seed varieties, frugal tools, and localized pest control techniques. The core components of grassroots innovation include:

- **Localized Deep Knowledge:** Experienced farmers leverage cultural practices, local climates, and soil characteristics to find adaptable solutions. This indigenous knowledge is often gathered and refined over generations.
- **Cost-Effectiveness:** Grassroot innovators utilize affordable, locally available materials to solve immediate problems. While these & "frugal" innovations remain localized because they lack modern scientific validation, integrating them into the broader agricultural framework is essential for sustainable growth.

Strategic Implementation Framework

To realize the potential of Agriculture 4.0 at the grassroots level, a localized implementation strategy is required:

a. **Digital Platforms and Local Data Centers:** A digital infrastructure must be developed to store and share indigenous knowledge, local soil profiles, and grassroot innovations. This platform should be accessible via mobile devices in local languages, providing farmers with weather forecasts, crop-related chatbots, and predictive analytics based on their specific inputs.

b. **Implementation of Precision Farming:** Provide low-cost, AI-driven IoT sensors to provide real-time field data. Additionally, training workshops are necessary to provide farmers with hands-on experience in utilizing drones and automated irrigation scheduling.

c. **Frugal Prototyping and Upgrading Local Tools:** Establish rural agricultural fabrication centers where farmers can collaborate with engineers to integrate AI sensors into existing local tools. These centers should offer scientific validation, patents, and recognition for these innovations within the manufacturing industry.

d. **Supply Chain Integration and Market Connectivity:** Utilize AI-driven platforms to connect farmers directly to regional markets. By matching local production with market demand in real study, the role of exploitative intermediaries can be minimized.

e. **Feedback Mechanism:** Strong feedback mechanisms are vital to improving agricultural AI. By pairing digital tools with on-ground interventions and analyzing geotagged crop images, AI systems can be validated and fine-tuned to suit local conditions.

Challenges in Implementation

Integrating AI with grassroots innovation faces several hurdles:

a. **Digital Divide:** Inconsistent internet connectivity and low smartphone penetration in rural areas hinder the adoption of AI-based solutions.

b. **Technological Sovereignty and Data Privacy:** Large amounts of agricultural data are often harvested by massive tech corporations. To prevent "digital data colonialism," policies must ensure that farmers retain ownership of their data and that local innovations remain protected from being exploited by foreign entities without compensation.

c. **Accessibility:** Low literacy rates in rural areas can hinder the adoption of complex AI systems; therefore, user interfaces must be simplified and localized.

Conclusion

Agriculture 4.0 is not limited to large corporations; local grassroots innovators are actively strengthening its foundation and driving its growth. To make smart farming more accessible, future studies must emphasize affordable sensor design, open-source software development, context-aware AI solutions, and multipurpose equipment crafted specifically for smallholder families. By intentionally merging Artificial Intelligence with grassroots innovations, India can achieve self-reliance in food security and stimulate economic growth. This synergy ensures that the "tools of the future" empower local communities, fostering sustainable development and paving the way toward a Vikshit Bharat.

Bridging the digital divide in farming Concept illustrations showing how high-tech AI applications can be seamlessly integrated into everyday rural agricultural practices.

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