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From **STABILIZATION** to **OPTIMIZATION**

How Industrial AI Is Redefining
Sugar and Ethanol Manufacturing



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AGRICULTURE UPDATES

Farmers to Receive 12% Interest on Delayed PMFBY Insurance Payouts

The Ministry of Agriculture and Farmers Welfare has issued stringent instructions enforcing a 12% annual interest penalty on insurance companies that fail to disburse crop loss compensation within the stipulated timelines under the Pradhan Mantri Fasal Bima Yojana (PMFBY). Under operational guidelines, empanelled insurance underwriters must process and credit approved claims directly to a farmer's bank account within 21 days of receiving loss assessment data and premium subsidy releases. Any default or procedural lag beyond this window now legally obligates the insurer to calculate and credit the 12% interest penalty alongside the principal claim amount directly via Direct Benefit Transfer (DBT).

The enforcement push addresses longstanding grievances regarding bureaucratic bottlenecks and delayed payouts that leave cultivators financially vulnerable after unseasonal rains, drought, or pest infestations. Union Agriculture Minister Shivraj Singh Chouhan underlined that the crop insurance architecture must serve as a dependable, zero-friction safety net rather than a protracted settlement process. To eliminate loopholes where delays stem from administrative friction, state governments are similarly held accountable to pay 12% interest on their share if state premium subsidies are not transferred to insurers within the designated cut-off dates.

To streamline transparency and track compliance, the government has integrated the mandate with the national Krishi Rakshak Portal and the central PMFBY claims dashboard. These digital interfaces automatically flag claims pending beyond the statutory threshold, triggering automated penalty calculations. District agriculture officers and state monitoring committees have been instructed to conduct weekly reconciliation audits to ensure insurance firms clear both the primary relief sums and accrued penal interest without requiring farmers to navigate burdensome appeals.



Centre Mandates District-Level Water Budgets to Guide Rabi Sowing Amid Regional Moisture Deficits

The Ministry of Agriculture and Farmers Welfare has directed state governments to formulate targeted, district-wise water budgets before finalizing sowing targets for the upcoming Rabi cropping season. The directive follows persistent uneven rainfall distributions during the late-monsoon window, which left key agrarian belts across Maharashtra, Karnataka, and parts of the southern peninsula with deficient groundwater tables and depleted storage across regional reservoirs. Rather than relying on uniform, state-wide targets, agricultural departments have been instructed to conduct granular assessments of both reservoir capacities and residual root-zone soil moisture. This decentralized planning framework aims to prevent mid-season crop failure, particularly for water-intensive winter staples, by ensuring acreage allocations match available local irrigation supplies.

Under the revised guidelines, district authorities are advised to steer farmers toward climate-resilient crop diversification, notably promoting oilseeds such as mustard and drought-hardy pulses over high-demand cereal crops. State agriculture extensions will deploy digital tracking mechanisms, integrating meteorological data and canal water-release timetables, to advise cultivators on optimal sowing dates. The government has stressed that miscalculating irrigation potential risks stunting early germination and depressing final yields. By synchronizing seed distribution and fertilizer allocations with verified water quotas, officials intend to curb distress while minimizing the depletion of vulnerable aquifers ahead of peak summer months.

The policy shift is being coupled with technical assistance and financial incentives to accelerate the adoption of micro-irrigation systems across water-stressed pockets. Farmers opting for drip and sprinkler irrigation, as well as those transitioning to less water-demanding crops, are slated to receive prioritized input subsidies and credit support. Central inter-ministerial teams have begun coordinating with state irrigation boards to monitor weekly water balances and ensure that localized water budgeting protects agricultural output without compromising domestic and drinking water reserves through the 2026–27 Rabi cycle.



Madhya Pradesh Enforces Nationwide Ban on Paraquat Dichloride Herbicide

The Government of Madhya Pradesh has enacted strict orders enforcing the nationwide prohibition on the highly hazardous chemical herbicide Paraquat Dichloride, issuing mandatory directives to seize, recall, and safely destroy existing commercial inventories across the state. The move follows the Government of India's cancellation of all existing registration certificates and the prohibition of fresh approvals under the Insecticides Act, 1968. Agriculture departments and district enforcement squads have been instructed to inspect retail agrochemical outlets, distribution hubs, and warehouses to prevent any clandestine sales, ensuring complete compliance across agricultural belts.

The stringent regulatory crackdown was accelerated by rampant off-label misuse of the herbicide, particularly by farmers spraying it directly onto standing summer moong (green gram) crops to force rapid pod-drying and hasten field clearance for kharif preparations. Medical experts and regulatory authorities raised alarms over severe public health risks, noting that Paraquat Dichloride is an acutely toxic chemical linked to irreversible respiratory failure, multi-organ breakdown affecting the liver and kidneys, and neurotoxic damage. Because the compound has no known medical antidote, direct exposure during manual spraying poses extreme hazards to farm laborers, while toxic residues left on harvested pulses threaten consumer food safety.

Under the enforcement guidelines, agrochemical manufacturers and dealers holding unsold stocks are required to surrender registration documentation to the Central Insecticides Board and Registration Committee (CIB&RC) and carry out verified safe disposal procedures under official oversight. The state agriculture department has also rolled out field-level advisories urging growers to adopt safe, mechanically assisted harvesting methods and registered botanical or eco-friendly alternatives. By aligning state enforcement with the national phase-out, authorities aim to eliminate toxic chemical exposure from the pulse supply chain and align domestic agricultural safety standards with global norms, where the chemical is already banned across roughly 70 nations.



Basmati Freight to Middle East Drops by 74% Under New Trade Routing Initiative

Indian Basmati rice exporters have secured a massive reduction in ocean shipping costs following a strategic bulk-shipping logistics initiative pioneered by the Indian Rice Exporters Federation (IREF). Under the new charter arrangement, freight charges for Basmati shipments to key West Asian gateways—most notably Iraq’s Umm Qasr Port—plunged by approximately 74%, dropping from prohibitive peaks of \$350 per tonne down to just \$90 per tonne. The logistical breakthrough bypasses expensive and scarce containerized freight by shifting to chartered break-bulk vessels, effectively shielding domestic grain traders from soaring maritime insurance premiums and transit surcharges triggered by recent regional geopolitical volatility along Middle Eastern sea-lanes.

The initiative directly safeguards India’s commanding agricultural trade footprint in West Asia, which represents roughly 70% of the country’s total Basmati export volume and accounts for trade valued at over ₹34,284 crore annually. In the inaugural deployment under this program, three large bulk carriers—handling an aggregate of more than 102,000 metric tonnes of premium rice—were commissioned to streamline port-to-port deliveries. By consolidating consignments from multiple export houses under a unified charter framework, the industry has eliminated middle-tier container leasing markups, averted severe turnaround bottlenecks at congested transshipment hubs, and significantly truncated overall delivery turnaround times.

Trade leaders and market analysts project that this 74% transport savings will sharply enhance the price competitiveness of Indian aromatic rice against emerging global competitors while boosting farmgate procurement realizations across Punjab, Haryana, and western Uttar Pradesh. Operating under the broader industry banner of “One Nation, One Trade, One Policy,” the IREF plans to replicate this dedicated bulk-charter mechanism across other key Gulf Cooperation Council (GCC) destinations, including Saudi Arabia, the United Arab Emirates, and Oman. By insulating agricultural supply chains from volatile ocean freight spikes, the model establishes a resilient logistics blueprint for India’s agri-commodity trade ahead of the peak winter export window.



IIT Ropar's ANNAM.AI Expands AI Weather & Agronomic Advisory Across Northern States

The Indian Institute of Technology (IIT) Ropar has expanded the deployment of its indigenous agricultural intelligence platform, ANNAM.AI, across northern agrarian belts including Punjab, Haryana, and western Uttar Pradesh. Conceived under the Centre of Excellence in AI for Agriculture with backing from the Ministry of Education, the initiative operates as an open Digital Public Infrastructure (DPI) aimed at transforming traditional farming into predictive, climate-resilient agriculture. By combining dense Internet of Things (IoT) field sensors, satellite climate models, and multilingual machine learning frameworks, the platform bridges critical information gaps for smallholders facing erratic rainfall, unseasonal temperature surges, and shifting pest dynamics.

At the operational core of the platform is the Micro Climate Intelligent Infrastructure (MCII), a high-density network of automated weather stations that delivers plot-level meteorological forecasts rather than broad district-wide averages. This real-time climate data feeds directly into the Annam Chat Engine (ACE) and KrishiAI computer-vision modules, which evaluate soil moisture, predict disease outbreaks, and diagnose pest infestations from smartphone photos. The system generates customized advisories in regional vernaculars—ranging from precise sowing dates and variable-rate fertilizer dosages to optimal irrigation schedules—helping farmers mitigate seasonal yield volatility by an estimated 20% to 30%. To ensure field-level adoption ahead of the peak winter planting window, IIT Ropar is scaling collaborations with state agriculture departments, regional Krishi Vigyan Kendras (KVKs), and Farmer Producer Organisations (FPOs). The expansion model emphasizes seamless data interoperability, linking with national digital assets such as Soil Health Cards and PM-KISAN databases.



ICAR Decodes Advanced Pigeon Pea Genome Map to Fast-Track Climate-Smart Pulses

In a major milestone for indigenous agricultural biotechnology, scientists at the Indian Council of Agricultural Research (ICAR) have successfully decoded India's first complete, high-resolution Telomere-to-Telomere (T2T) reference genome for pigeonpea (arhar/tur). The breakthrough, led by the ICAR-National Institute for Plant Biotechnology (NIPB) in collaboration with national pulse research institutes, resolves long-standing gaps in the crop's genetic blueprint. By mapping 752.65 million base pairs across all 11 chromosomes—including previously uncharted centromeric and repetitive regions—the assembly provides an ultra-precise molecular atlas of one of India's most essential dietary protein sources.

The advanced genomic map directly addresses structural vulnerabilities in domestic pulse production, where pigeonpea is overwhelmingly cultivated under unpredictable, rainfed conditions. Agricultural breeders can now pinpoint exact genetic loci governing high-value agronomic traits, notably deep-root moisture efficiency, extreme heat tolerance, and resistance to destructive biological threats like Fusarium wilt and sterility mosaic disease. By eliminating guesswork from traditional multi-season selection cycles, the gap-free assembly empowers researchers to leverage CRISPR-based gene editing and marker-assisted breeding, substantially shortening the development timeline for high-yielding, climate-resilient cultivars from over a decade to just a few years.

This scientific leap lands as a cornerstone for the Government of India's Mission for Aatmanirbharta in Pulses, which aims to achieve national self-sufficiency and eliminate import dependence by 2030–31. Pigeonpea yield stagnation has historically exposed domestic markets to acute retail price volatility whenever monsoon rainfall patterns falter. By translating fundamental plant genetics into field-ready seed varieties, ICAR's complete genome architecture equips Indian farmers with hardier crops capable of sustaining bumper yields amid escalating climate extremes, reinforcing both long-term food security and smallholder farm profitability.



From **STABILIZATION** to **OPTIMIZATION**

How Industrial AI Is Redefining
Sugar and Ethanol Manufacturing



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SMART PRODUCTION



AI F

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India's sugar and ethanol manufacturing sector is entering a new phase of digital transformation, with Industrial Artificial Intelligence (AI) emerging as a critical enabler of operational efficiency, predictive decision-making and sustainable production. As manufacturers navigate fluctuations in raw material quality, changing operating conditions, energy requirements and equipment performance, traditional automation and operator-led decision-making are increasingly being complemented by AI-driven operational intelligence.

The real opportunity lies not simply in digitising manufacturing processes, but in enabling plants to operate more consistently, anticipate disruptions and make better decisions across the production cycle. For sugar mills and distilleries, this journey begins with stabilisation and progresses towards optimisation.

Moving Beyond Traditional Automation

Sugar and ethanol manufacturing involves a complex network of interconnected processes, including cane crushing, extraction, clarification, evaporation, crystallisation, centrifugation, fermentation and distillation. A disruption in one area can affect the entire production chain, influencing recovery rates, throughput, steam balance, product quality and operating costs.

Historically, manufacturers have relied on operator experience, laboratory testing, standard operating procedures and conventional automation to manage these variables. While these approaches remain essential, Industrial AI introduces an additional layer of intelligence by continuously analysing plant data, identifying subtle changes in process behaviour and detecting deviations before they translate into measurable production losses.

This shift enables manufacturers to move beyond retrospective reporting towards proactive decision-making. Instead of merely understanding what happened, operational teams can identify what is changing, anticipate its potential impact and take corrective action before performance deteriorates.

For process industries, stabilisation is the first step towards achieving this objective. By reducing avoidable variability and maintaining consistent operating conditions, manufacturers can establish a reliable foundation for improving productivity, recovery and energy efficiency.



Predictive AI: From Reactive Maintenance to Proactive Operations

One of the most significant applications of Industrial AI is its ability to identify early warning signs of equipment deterioration and process instability. Conventional monitoring systems typically generate alarms when individual parameters cross predefined thresholds. However, operational problems often develop before these limits are breached.

A temperature reading, pressure level or flow rate may appear normal in isolation, while the relationship between multiple variables indicates an emerging issue. AI can analyse these interconnected patterns to identify anomalies that may otherwise go unnoticed.

This capability supports several aspects of plant performance, including early anomaly detection, prediction of potential downtime or quality losses, identification of possible root causes and recommendations to restore stable operating conditions.

Once a consistent operating baseline has been established, AI can help manufacturers identify improved operating ranges and recommend adjustments to enhance throughput, product quality, recovery and utility consumption while accounting for plant constraints.

The distinction between stabilisation and optimisation is particularly important in process manufacturing. Attempts to improve individual performance indicators without first addressing underlying instability can result in temporary gains that are difficult to sustain. A more structured approach enables manufacturers to reduce disruptions first and then build on that stability to achieve lasting improvements.



Data-Driven Planning for Smarter Manufacturing

Operational excellence also depends on the ability to align production planning with changing plant conditions. In the sugar industry, production decisions are influenced by several factors, including cane availability, crop maturity, expected crushing volumes, feedstock quality, recovery expectations, logistics and market demand.

Once production begins, these variables interact with actual operating conditions. Crushing rates, process stability, steam availability, boiler performance, equipment health, ethanol production routes and downstream operations can all influence the plant's ability to meet its targets.

Traditional production plans may struggle to accommodate these continuous changes. Data-driven planning offers a more dynamic alternative by connecting forecasts and production targets with real-time operational intelligence.

AI can help manufacturers assess achievable output under current conditions, identify bottlenecks affecting performance and anticipate where process instability could disrupt production schedules. It can also support timely corrective decisions to protect operational targets.

By integrating forecasting, plant operations and decision-making, manufacturers can move from static planning towards a more responsive production environment. This improves planning accuracy and enables management teams to make decisions based on actual plant performance rather than assumptions that may no longer reflect operating realities.

Industrial AI and the Drive Towards Sustainable Manufacturing

For sugar and ethanol manufacturers, sustainability is closely linked to operational efficiency. Process instability can lead to higher consumption of steam, power, water and chemicals, alongside increased raw material and product losses.

Industrial AI can help identify abnormal variations in resource consumption, establish a stable performance baseline and detect when a plant begins to deviate from its expected operating range. With this foundation in place, manufacturers can identify opportunities to improve resource utilisation and reduce waste.

Key areas of application include steam economy, extraction efficiency, process water consumption, fermentation performance, distillation efficiency, energy balance and product recovery.



Importantly, these processes cannot always be optimised independently. For instance, increasing imbibition may improve extraction but can also raise the downstream evaporation load and steam demand. Similarly, improving distillation performance in one section may increase overall energy intensity if the wider production system is not considered.

Industrial AI can help evaluate such trade-offs across interconnected operations and support decisions that align with the overall objectives of the plant. Rather than focusing exclusively on individual departmental performance indicators, manufacturers can take a broader view of resource efficiency, production quality and operating costs.

This creates an opportunity to shift sustainability management from retrospective measurement towards more proactive, data-informed operational decisions.

The Road Towards Autonomous Manufacturing

The future of manufacturing will be shaped not only by the extent of automation but also by the quality and consistency of operational decisions. Advanced factories will increasingly combine process expertise, digital infrastructure and AI to create continuously improving decision environments.

This evolution can be understood through five stages: visibility, prediction, stabilisation, optimisation and autonomous execution.

Visibility enables manufacturers to understand what is happening across the plant. Prediction helps anticipate potential deviations, equipment risks and production losses. Stabilisation brings operations back to consistent performance levels, while optimisation identifies better operating decisions across multiple parameters and constraints. Autonomous execution represents the next stage, in which selected decisions can be implemented automatically within clearly defined boundaries.

Many manufacturing facilities are still developing their capabilities in visibility and prediction, while others are beginning to explore more advanced, prescriptive intelligence. The next significant step is to move from identifying and correcting deviations towards consistently optimising overall plant performance.

However, fully autonomous manufacturing remains a longer-term ambition, particularly in complex process industries where safety, equipment constraints.





Why

INDIA'S AGRI-TECH STORY

Must Move Beyond Farmer Advisory to Actual Production Technology

Turmeric, Ashwagandha, Boswellia, Coleus, Moringa, Ginger, Holy Basil, Silymarin and countless other botanicals have long been woven into the country's traditional health practices.

We all have the world's smartest fitness coach on our wrist and in our pockets, always nudging us to move more, drink water, and get enough sleep. Yet, for all those reminders, only a handful of us actually become fitter. Why? Because knowing what to do is never quite the same as being able to do it.

For the past ten years, India's agricultural sector has faced exactly this problem. We have given millions of farmers access to weather forecasts, pest warnings, and mandi prices, which is indeed a major advance. Yet when the rains don't arrive, crops still die. Although our farmers know more than ever, their fields are just as vulnerable.

Much of the sector's energy, talent, and money has poured into this information layer: advisory apps, input marketplaces, market linkage, and farm fintech. It made sense - software is cheap to build, fast to spread, and India's information gap was

real. But cracks are showing. In 2025, Indian agri-tech startups raised only \$202 million across 36 deals, down nearly 25% from the year before, and a shadow of the \$840 million raised in 2022. The capital flow tells us something: the easy wins are over.

Advice only works when you have the means to follow it. A doctor's prescription is useless if the pharmacy is empty. Telling a farmer with 1.08 hectares, the national average, to irrigate on Tuesday is pointless if his borewell ran dry last summer. For India's 86% small or marginal farmers, the real bottleneck isn't knowledge. It's capability.

We have digitized the advice and left the farm untouched.



Pradeep Ram
Co-Founder
AgResearch Labs

The obstacles slowing Indian agriculture are firmly in place. Although about half the workforce is engaged in farming, agriculture accounts for only 17% of GDP. In 2024, cereal production exceeded the world average, 3,633 kg per hectare compared with 3,375 kg; yet because India is the world's second-largest producer of both rice and wheat, this is by no means a great achievement. India draws more groundwater than the United States and China combined, yet only 12% of the 74 million hectares of irrigated land use efficient drip or sprinkler systems. At the same time, heatwaves are occurring earlier, and the monsoon is becoming more unpredictable every year.

None of these is a problem that an app can solve. A weather alert can't make it rain; a pest notification won't save a crop. The real issues are stubbornly rooted in the soil.

Consider the progress that all the other industries have made. Indian manufacturing did not become world-class due to factory owners obtaining shiny dashboards; instead, it was achieved when they purchased better machines, enforced stricter processes, and established controlled environments. The dashboards came afterwards in order to monitor what the machines had accomplished. In the case of agri-tech, however, they have tried to reverse the situation: putting the dashboard first and never getting around to the machine.

Production technology is the missing machine. It's anything that turns land, water, or labor into more: controlled-environment systems that free yield from the mercy of the weather, precision tools for water and nutrients, machinery sized for small plots, and post-harvest tech right at the farm gate.

Aeroponics, a method in which the roots of the plants hang in the air and are fed by a carefully controlled nutrient mist, demonstrates just how great a difference this change can make. With no soil, most pests and diseases disappear, along with the need for pesticides. Instead of being lost to the ground, the water is recirculated over and over again. Since all

inputs are measured and controlled, a large harvest is not a matter of luck; it is the result of engineering.

At AgResearch Labs, we have adapted this science for the past 14 years to meet India's unique combination of heat, humidity, and price pressure. Our technology lets us produce nearly a ton of leafy greens each acre every day. The true point isn't the figure; it's the evidence: once you re-engineer the farm, you end up rewriting the maths of agriculture.

Certainly, we should be frank about the limitations. Farmer advisory won't be replaced by production technology, and it shouldn't be. Good infrastructure performs better when it has access to information; the two are partners, not competitors. The controlled environments won't take the place of the wheat and paddy fields which form the basis of our food security. And if production technology overlooks economic considerations, it will fail. Several impressive indoor farms in the West have failed, not because their crops failed, but because their business models didn't work. India requires technology that is suited to Indian conditions and Indian costs.

So, what will it take for production technology to really scale? Three things must change.

First of all, the capital used must be suitable for the type of asset involved. A farm system is a kind of hardware which lasts over a number of years, not an app that you have to subscribe to on a monthly basis. It requires blended finance, long-term credit, and the kind of funding typical of infrastructure, not simply venture capital looking for quick returns from software.

Second, policy should recognize actual results. Subsidies for drip irrigation, polyhouses, and farm machinery should also be provided for soilless and controlled-environment systems and should be linked to measurable achievements such as the amount of water saved, the production of residue-free crops, and higher yields per acre.

Thirdly, ownership should be shared. Farmer producer organisations, agri-entrepreneurs and rural



youth should be able to co-own and manage the production units, just as custom hiring centres made tractors accessible to people who never could have bought one themselves. In this way, farming can become a career that young Indians choose rather than one that they run away from.

The initial wave of Indian agri-tech posed the question of how it might help farmers make better

decisions; the following, more ambitious wave should ask how it can help farms to produce better.

We've taught the farmer what to do. Now, it's time to give the farm the power to do it.

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SMART BEEKEEPING

Artificial Intelligence, Sensors and IoT Changing the Face of Apiculture

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As far back as beekeeping can be recalled, the only way to determine the state of a colony was to open it up on smoke, disturbance, and interruption, usually to see it for no more than five minutes. The alternative with precision beekeeping or “smart” beekeeping is to install sensors inside or under the hive that monitor temperature, weight, sound or humidity, and transmit the data to an app that the beekeeper can access remotely. The hive speaks softly, the beekeeper listens, and he or she decides which hives should be visited. The technology is not a way for the beekeeper to replace their eye and hands, but instead it is a way to reduce how often the beekeeper needs to put their hands in the hive.

What's the smart part of it?

A sensor in the hive relays temperature, weight, sound and humidity data to a wireless network, often long-range and low-power, to a gateway and on to a cloud-based dashboard that the beekeeper can access anywhere. It is not in this chain that the bees are managed; it is merely brought to the surface early that something is worthwhile of knowing. These systems are described as being used for some form of “decision support”, not as automation: when the

weight rises, a temperature drift occurs, or less traffic comes in at the entrance, it is a reminder to check, not a diagnosis. While someone is opening the box and determining what should be done, they narrow down which hives need attention and approximately when.

Sensors Inside the Hive

Four types of sensors have been introduced into operational apiaries. The most studied are the temperature sensors: a healthy brood nest will maintain a stable temperature and changes in the stability of this temperature have been correlated with colony strength but not with what caused a change. Humidity sensors measure moisture associated with brood development and honey storage and are most useful when used in conjunction with other data. Underlying the hive with a weight sensor, which is essentially a scale, is arguably the most useful instrument in precision apiculture; a rising curve indicates nectar income, a flattening or falling curve indicate the cessation of income, and/or the colony is utilizing its stores. Weight alone, however, does not give an exact determination of the amount of extractable honey in the supers. One of the less proven tools at their disposal is an acoustic

sensor, which has identified patterns of sound related to swarming and queenlessness. The newer entrance camera employs computer vision to count bee traffic, as a rough measure of foraging activity.

Digital Tools and Their Potential Uses in Beekeeping



AI capabilities and limitations

Artificial intelligence is primarily employed to identify patterns over several years of sensor data, which humans could not possibly have been able to scan. AI is largely used to discern the “normal for the season” from the “worth a second look” with the patterns seen over many years of sensor data. In working systems, image-recognition software which counts entrance traffic or estimates daily weight gain is already working. Reliable AI models that can diagnose a brood disease from a photo or predict a swarm days ahead, have not yet entered the market



as commercial products, but are still research. The image-based method for identification of Varroa mites from bee or sticky debris is early and experimental, but has shown promise; the sugar-shake or alcohol-wash test is still the practical field-based method.

The importance of this for Indian Beekeeping.

India is one of the major producers of honey in the world, beekeeping is encouraged by various initiatives like National Beekeeping and Honey Mission, and it involves both large-scale migratory apiaries and backyard beekeeping. In the case of a migratory beekeeper who cannot make weekly visits to all of their apiaries, a remote alert could be useful in deciding which apiary should be visited next; however, the connectivity, feasibility of powering the sensors and the cost are real issues for many smaller and medium sized beekeepers.

Beekeeper Plus Technology

The appeal is simple: no need to conduct disruptive inspections, a continuous record rather than notes and earlier warning when a change occurs. The expenses are just as genuine sensor and data plan prices build up on slender margins; battery maintenance and solar panel maintenance take place; batteries or solar panels may be dropped and sensors could become misaligned, yielding a data set that appears certain but is actually incorrect, and which may be worse than having none at all.

This is not a step toward self-supporting apiaries. The technology cuts down the amount of area to search and the decision on what to do once found remains with the beekeeper. The direction apiculture seems to be taking is with beekeeper + technology, not beekeeper vs technology.

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ENERGY EXPENDITURE

Techniques of Agricultural Workers

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Agricultural work remains among the most physically demanding forms of human labour, particularly in regions where manual methods continue to dominate small and marginal landholdings. Understanding precisely how much physiological effort each farm operation demands are essential for informed nutrition planning, ergonomic tool design, and equitable labour policy. This article presents an overview of the principal scientific techniques used to measure and classify the energy expenditure of agricultural workers, including oxygen consumption rate analysis, heart rate monitoring, the doubly labelled water method and composite drudgery indices, with reference to findings from field studies conducted among Indian farm workers.

Introduction

Manual agricultural labour continues to constitute a substantial share of farm power in developing economies, even as mechanisation gradually advances. Field operations such as transplanting, threshing, weeding and load-carrying impose considerable cardiovascular and musculoskeletal

demands on workers and repeated exposure to these demands over a working lifetime carries measurable health consequences. In response, agricultural physiologists and ergonomists have, over several decades, developed a range of standardised methods for quantifying the physiological cost of farm work. These methods serve three principal purposes: establishing realistic dietary energy recommendations for farming households, guiding the ergonomic redesign of hand tools and implements and informing the classification of agricultural occupations for wage and welfare policy.

Techniques for Measuring Energy Expenditure

Oxygen Consumption Rate (OCR)

The most physiologically direct field technique measures the volume of oxygen consumed by a worker during a task, typically using a lightweight mask connected to a portable gas-analysis apparatus. Because oxygen consumption can be converted directly into energy expenditure using established conversion factors, this method is regarded as highly reliable. In a field study of manual agricultural operations in Odisha, working heart rate and oxygen

consumption rate were recorded at approximately 136 beats per minute and 0.98 litres per minute for male workers during spade-based land preparation, with comparatively lower physiological demand observed during manual paddy transplanting.

How Scientists Measure a Farm Worker's Energy Cost

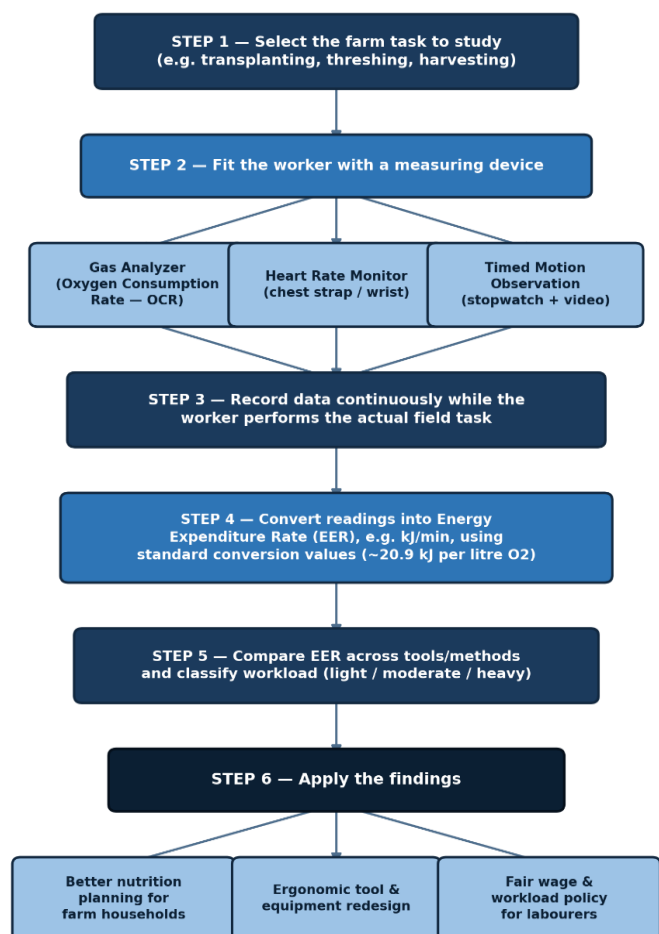


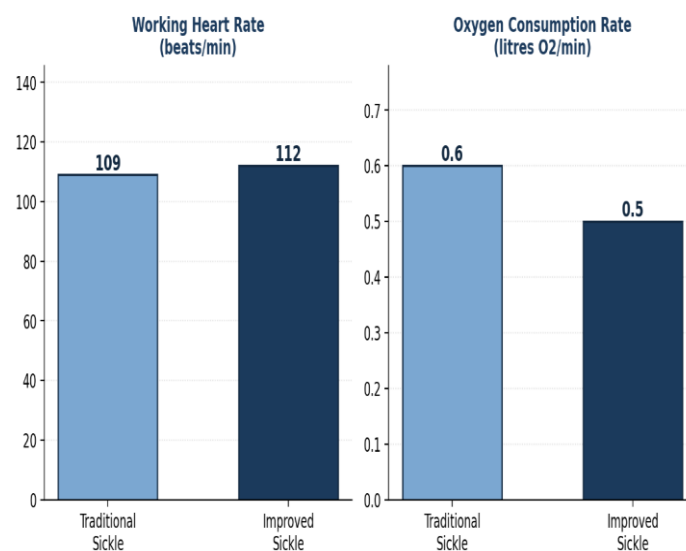
Figure 1. General workflow followed in field-based energy expenditure studies of agricultural workers.

Heart Rate Monitoring

Because heart rate rises in a broadly linear relationship with physical workload, continuous heart-rate recording is widely used as a practical proxy for direct gas analysis in field conditions. A comparative study of local and improved sickles used for paddy harvesting recorded a mean working heart rate and oxygen consumption rate of approximately 112 beats per minute and 0.5 litres per minute with the improved implement, compared with 109 beats per minute and 0.6 litres per minute for the traditional sickle, alongside a measurable increase in output

(Khadatkar, Potdar, Wakudkar, Narwariya, & Dubey, 2018). Such findings illustrate that ergonomic tool redesign can improve productivity without proportionately increasing physiological strain.

Traditional vs. Improved Sickle: Physiological Response During Paddy Harvesting

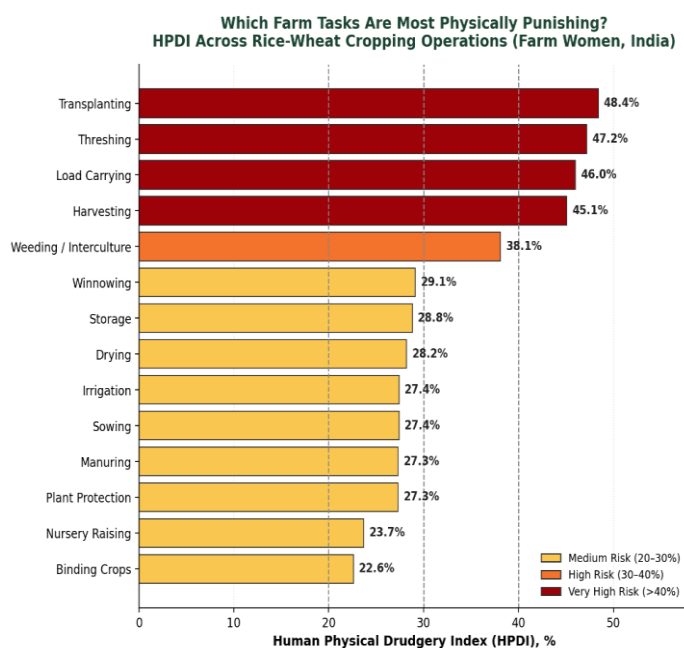


Source: Khadatkar, Potdar, Wakudkar, Narwariya, & Dubey (2018), Indian Journal of Extension Education, 54(1), 104-107

Figure 2. Working heart rate and oxygen consumption rate for traditional versus improved sickles during paddy harvesting.

Composite Drudgery Indices

Beyond direct energy accounting, researchers have developed composite indices that integrate physiological load with postural strain, task difficulty and repetitive motion into a single measure of occupational burden. The Human Physical Drudgery Index (HPDI), for example, is derived from seven weighted parameters, including time spent on an activity, its seasonal frequency, difficulty, postural demand, frequency of postural change, associated discomfort and load or force involved. In a 2024 study of women farmers engaged in rice-wheat cropping systems in India, this index was applied across fourteen distinct farm operations; transplanting, threshing, load carrying and harvesting were each classified as posing very high physiological risk, while operations such as nursery raising, sowing and storage remained within a moderate risk band.



Source: Joshi, Mahra, Jethi et al. (2024), *Frontiers in Sustainable Food Systems*, 8:1346980 (Reference 7)

Figure 3. Human Physical Drudgery Index scores across fourteen farm operations, showing transplanting, threshing, load carrying, and harvesting as the most physiologically demanding tasks. Source: Joshi et al. (2024).

The same investigation reported the underlying physiological data behind these rankings: paddy transplanting elevated working heart rate from a resting baseline of approximately 80 beats per minute to 127 beats per minute, corresponding to an energy expenditure rate of roughly 11.5 kilojoules per minute, placing the task within the “heavy” workload category. Threshing produced an even greater physiological demand, with heart rate rising to nearly 131 beats per minute.

Classification of Physical Workload

Field measurements of heart rate and energy expenditure rate are conventionally translated into standardised workload categories, allowing comparison across tasks, tools, and worker populations. Table 1 presents the threshold values established for Indian agricultural workers by Nag and Chatterjee (1981), subsequently adopted in later ergonomic assessments of farm labour.

Table 1. Classification of physical workload based on physiological response.

Workload Category	EER (kJ/min)	Working Heart Rate (b/min)	% of VO ₂ max
Very Light	Up to 5.0	Up to 90	—
Light	5.0 – 7.5	91 – 105	< 25%
Moderate	7.6 – 10.0	106 – 120	Up to 50%
Heavy	10.0 – 12.5	121 – 135	Up to 75%
Very Heavy	12.6 – 15.0	136 – 150	Above 75%
Extremely Heavy	Above 15.0	Above 151	—

Discussion and Practical Implications

The convergence of evidence from oxygen consumption studies, heart-rate monitoring and composite drudgery indices consistently identifies transplanting, threshing, harvesting and load-carrying as the most physiologically demanding operations in manual cropping systems, often imposing energy demands comparable to or greater than those encountered in industrial labour. These findings have important practical implications. From a nutritional perspective, they highlight the need to align dietary energy recommendations for agricultural households, particularly women farm workers, with objectively measured workloads rather than generic estimates. From an engineering perspective, the demonstrated reductions in working heart rate and energy expenditure achieved through improved implements, such as the redesigned sickle discussed above, provide strong evidence for the development and wider adoption of ergonomically optimised farm tools. From a policy perspective, standardised workload classification could provide a scientifically defensible basis for establishing



occupational health guidelines, appropriate work-rest schedules and equitable wage determination within the agricultural sector.

Conclusion

The physiological measurement of agricultural labour has matured into a well-established scientific discipline, offering a range of techniques suited to

different research contexts, from portable gas analysis and heart-rate telemetry to isotope-based total energy expenditure assessment and composite drudgery indices. Continued application of these methods remains essential to informing nutrition policy, guiding ergonomic tool design, and safeguarding the health and productivity of the agricultural workforce.

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Rise of

AGRI-STARTUPS IN JAMMU & KASHMIR

A New Wave of Agricultural Entrepreneurship

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Every autumn, the orchards of Jammu and Kashmir turn into a sea of red and gold as apples are picked, packed and sent to mandis hundreds of kilometers away. For generations, this has been the rhythm of life here sow, tend, harvest, sell and hope that the price holds. But walk through the same orchards today and you will also find a young grower checking pest alerts on a mobile app, a woman near Anantnag packaging saffron threads in branded glass jars for an online store, or a graduate in Jammu running a cold-chain van that delivers cherries to a city three states away. Quietly and without much fanfare, agriculture in Jammu and Kashmir is being reshaped by its own people not simply as a livelihood inherited out of necessity, but as a business pursued with ambition.



Apple orchard in Jammu & Kashmir



Saffron, a high-value agricultural product

From Farms to Front Pages

The Union Territory's natural strengths apples, walnuts, saffron, cherries, almonds and off-season vegetables have always given it an edge in horticulture. What is changing is what happens to that produce after it leaves the field. Instead of moving through long, multi-layered supply chains, a growing number of young entrepreneurs are creating more direct routes to consumers: farm-to-home vegetable and fruit box subscriptions, saffron and honey brands sold online, mushroom units established in unused spaces at family homes, and small processing enterprises that turn surplus fruit into jams, squashes and dried snacks rather than allowing it to go to waste.

What makes this wave particularly interesting is who is leading it. These are not only outside investors bringing capital; they include sons and daughters of farmers, agriculture graduates and homemakers who have grown up around these crops and now view them through an entrepreneurial lens better packaging, a story worth telling and a price that better reflects the labour behind the product. Women, in

particular, are building a stronger presence in food processing, saffron value addition and handicraft-linked agri-produce, transforming household-level skills into income-generating enterprises.

The Support System Behind the Shift

This transformation has not happened in isolation. Agricultural universities such as SKUAST-Jammu and SKUAST-Kashmir run incubation and business-mentoring initiatives that can help students and farmers move from an initial idea towards a functioning enterprise, including support in areas such as business planning and regulatory requirements. Government support has also expanded through initiatives associated with the Jammu & Kashmir Rural Livelihood Mission, the Horticulture Department and central programmes such as the Agriculture Infrastructure Fund, which aim to improve access to finance and infrastructure.

Technology has quietly become another important part of this transformation. Farmers no longer have to rely only on periodic visits to the mandi to learn about prevailing prices; phones and digital platforms can provide information more quickly. Orchard owners are experimenting with sensor-based irrigation and pest advisories, while young agri-entrepreneurs increasingly use Instagram and WhatsApp to connect with customers and showcase their products. In a region where distance from markets has long been a challenge, technology is helping to narrow that gap.

Challenges That Still Remain

The story, however, is not without its hurdles. Small and fragmented landholdings can make it difficult to achieve the scale required for a viable business. Cold-storage and processing infrastructure, although improving, remains concentrated around a few towns, leaving many remote areas underserved.

Seasonal connectivity and road disruptions can also turn a good harvest into a loss within days when perishable produce cannot be transported in time. For many first-time entrepreneurs, another barrier is the paperwork and time involved in accessing formal credit a challenge that can discourage promising ventures before they have an opportunity to grow.

Bridging these gaps will require more than one-time schemes. It calls for sustained investment in rural cold chains and roads, simpler and faster access to institutional finance for young entrepreneurs, including those without substantial collateral, and stronger, continuous hand-holding among universities, government agencies and entrepreneurs so that innovations tested in institutions can reach farmers while they remain relevant.

The Road Ahead

What is unfolding in Jammu and Kashmir is more than a collection of individual success stories; it represents the early shape of an emerging agri-entrepreneurial movement. Every young person who chooses to build a saffron brand instead of migrating for a job, or a cold-chain enterprise instead of leaving the family orchard, contributes to a rural economy that has long depended on agriculture but has faced persistent challenges in capturing greater value from it.

With continued policy support, easier access to finance and mentorship that extends beyond the classroom, this new generation has the potential to bring fresh energy to Jammu and Kashmir's agricultural economy. The soil remains the same; it is the ambition growing in it that is changing.

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FROM BEES TO BOTS

The Rise of Automated Pollinators

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Importance of pollination in fruit and vegetable production

Pollination is considered to be one of the most important biological processes responsible for the production of fruits and vegetables. The pollen grains are transferred from the anther to the stigma of the flower, which usually leads to fertilisation. Pollination triggers the development of seeds and fruits in many crop plants. Therefore, the efficiency of the process is the determining factor in fruit setting.

Role of insects in natural pollination

Insect pollinators play a crucial role in the process of natural pollination as they promote the sexual reproduction of flowering plants and ensure the stability and sustainability of agroecosystems. Pollinators such as honeybees and bumblebees (bees), monarch butterflies (butterflies), birds, sphinx moths (moths), dronefly (flies), rose chafer beetle and fig beetle (beetles), paper wasp and tarantula hawk wasp (wasps), argentine ant (ants) and thrips

transfer pollen grains from anthers to stigmas of flowers, ensuring fertilisation and fruit/seed production. Therefore, the process is very important for the survival of plant species and preservation of biodiversity and plays a significant role in agricultural sustainability.

According to different estimates, 75% of the main insect-pollinated crops account for about 35% of global food supply, mainly in fruits, vegetables, nuts and a few oilseed crops. Examples of the fruit crops which are important in terms of insect pollination are apples, almonds, cherries, peaches, melons and blueberries, as these crops require insects for effective fruit set and yield. In addition, there are some important insect-pollinated vegetables of families such as Cucurbitaceae (pumpkins, squashes, cucumbers), Cruciferae (cauliflower, cabbage, broccoli) and Apiaceae (carrot, celery, parsnip). Furthermore, successful pollination leads to favourable fruit characteristics (size, shape, colour, uniformity), as well as improved quality and marketability. Thus, insect pollination facilitates both

ecological and economic benefits, particularly in pollinator-dependent fruit and vegetable production.

Why is automated pollination needed?

It is certain that efficient pollination is essential in optimising crop productivity. Despite the well-known role of pollinators, they are still exposed to the following challenges-

1. Reduction in pollinator population

The pollinator population has declined worldwide, and about 87% of the world's flowering plants and 87% of global food crops are dependent on pollinators for seed formation. The decline in the pollinator population results in adverse effects on biodiversity conservation and food security. According to reports, the reduction in the pollinator population may have a negative effect on 35% of the total global crop production as well as 60-75% of the horticulture crop species, including fruits, vegetables, and nuts.

Climate change is the largest threat both to pollinators and mankind, and it is one of the most challenging problems to be addressed. Climate change will impact the amount and availability of water and temperature, making fewer resources available for pollinators, reducing the lifespan of the larvae and/or adult and altering the habitat.

2. Hurdles in protected cultivation

Pollination, an important determinant of agricultural productivity, has challenges in a controlled environment, which necessitates the need for innovative methods. In open field cultivation, the wind and insects cause vibrations to release the pollen grains. However, pollination in greenhouses requires either pollinators or some other activity for fruit setting and quality. In addition, the lack of bee/wind pollination in greenhouses due to their controlled environment has created a need for other pollination systems.

From manual to automated pollination: a notable transition

1. Introduction and methods of traditional pollination

1.1 Natural pollination- It requires dependence on vectors such as water, wind and animal pollinators for a cross-pollination process to occur in plants. Among these, animal pollinators hold the largest share, providing pollination services for more than 75% of staple crops and 90% of flowering plants of the world. Also, within them, insect pollinators are the predominant ones, which include examples such as honeybees, solitary bees (*Xylocopa*, *Andrena*, *Halictus*), bumblebees, butterflies and wasps.

1.2 Artificial/manual pollination: Manual pollination, where paintbrushes, electric pollen dispersal devices, or air blowers are used to pollinate plants, is one of the most common techniques for dealing with pollination deficit during protected cultivation. Nevertheless, this technique is highly laborious and costly despite providing controlled crossing.

The rise of robots in pollination

1. Technological innovations (robotics/computer vision/AI/sensors/IoT/Drones)

1.1 Unmanned aerial vehicles (UAVs)/Drones

The use of drones has become popular as they are the paradigm for UAV's that are autonomous and can be used with or without artificial intelligence for the purpose of artificial pollination of crops. Since they are flying robots and easily available, drones are preferred over other robots. The devices used for drift pollination through drones can either be agricultural drones that have been modified or drones that are specifically designed for pollination purposes.

1.2 Drone navigation and control for pollination –

Depending on the application, drones can be navigated through-

- ✓ **Manual control-** The drone is navigated by a human pilot, who guides its flight towards the target flower.
- ✓ **Predefined flight path-** The drone navigates along a predetermined route based on the arrangement of fruit trees within the orchard to further facilitate pollen delivery.
- ✓ **Three-dimensional (3D) model- based navigation-** The orchard is initially surveyed by a scouting drone to create a 3D model of the environment of fruit trees, enabling the pollination drone to navigate the orchard.

- ✓ **Target selection-** The system selects the flowers suitable for pollination.
- ✓ **Flower localisation-** The position or coordinates of the selected flower are determined and stored in a database to guide precise pollen application.
- ✓ **Navigation and positioning-** It depends on the type of system designed. The robotic system (ground-based robots, robotic arms) or unmanned aerial vehicle/ drones move or positions itself accurately to perform pollen delivery.
- ✓ **Pollen delivery-** Pollen is delivered through appropriate mechanisms such as end-effectors (brush-based contact, vibration tool) or through a pollen delivery device (air jets, or wet and dry spraying systems).
- ✓ **Pollination-** The delivered pollen is deposited on the stigma, thereby accomplishing pollination.
- ✓ **Next target-** Monitoring and feedback systems assess how the system is working and guide it to the next targets (and so on), so it can be pollinated again and again.

1.3 Working of the automated pollination system

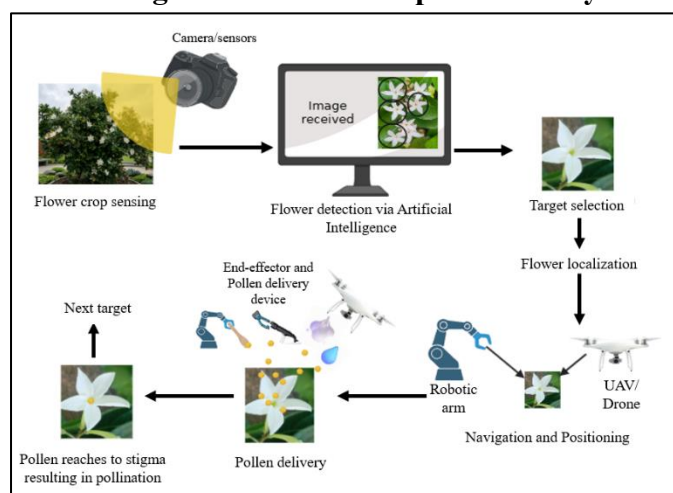


Fig. 1: General workflow of automated pollination system

Automated pollination involves the use of technology, such as robotic arms, ground robots and unmanned aerial vehicles (UAVs), to transfer pollen to the stigma of the flower, which reduces the need for manual labour. The step-wise workflow of automated pollination is as follows:

- ✓ **Crop/Flower sensing and image acquisition-** Vision cameras (RGB or ultra-compact) or sensors mounted on robots or drones capture images of flowers in the field.
- ✓ **Flower detection and recognition-** The captured images are transmitted to the AI classifier (flight-control node) or to the computer vision system, where it analyses the flower images and may recognise their developmental phases.

Table 1- Automated pollination in fruit and vegetable crops

S. No.	Fruit crops	Description
1.	Almond, pistachio, stone fruit, date palm	Dropcopter drone-based pollination system for aerial pollen distribution. It is provided as a fee-for-service pollination operation.
2.	Walnut	Aermatica 3D-Bly drone-based pollination system for aerial dispensing of dry pollen powder
3.	Apple	YOLOv5s-Im deep-learning model integrated into a drone platform for real-time detection of apple flowers during automated

		pollination.
4.	Date palm	AI-enabled drone-assisted pollination using YOLOv5/YOLOv8 for inflorescence detection and automated pollen spraying. It estimated reductions in labour and pollen use compared with manual pollination.
5.	Japanese pear	AI-enabled autonomous drone integrating flower-cluster detection, real-time kinematic global navigation satellite system (RTK-GNSS) navigation and electrostatic pollen spraying achieved fruit set comparable to manual pollination.
6.	Tomato	Mechanical shaking devices or vibrating pollination devices/robotic pollination have been used in greenhouse tomatoes for the release of pollen from the anthers. The pollination rate with the help of mobile robots equipped with a pollination mechanism is approximately around 7.5 seconds per flower. Moreover, there is an increase in tomato yield by 20% with a pollination robot in a 10- hectare pilot field, in contrast to manual pollination.
7.	Cucumber	For greenhouse cucumbers, the ShaQer mechanical pollination system, which is

		an automatic vibratory system, is a good alternative to manual pollination or where bumblebee-mediated pollination is challenging.
8.	Sweet Pepper/Bell Pepper	Adoption of hand-held mechanical pollinators and stereo vision combined with YOLO- based image processing helps to identify and locate the capsicum flowers at a suitable pollination stage.
9.	Watermelon	Utilisation of a 3D camera along with a linear actuator for pollination in watermelons is currently in the early stages of development

Challenges to Robotic Pollination

Although having several advantages such as a decrease in the need for labour (by 50%), precision in pollination using the machine's vision, an increase in crop yield and quality, and also acting as a better substitute for manual/hand pollination, there are certain challenges with the robotic technology that include the following:

- ✓ Higher costs associated with pollen delivery/robotic systems raise doubts about the pollen viability.
- ✓ Difficulty in recognising the flower from an aerial point of view owing to low resolution of the sensor reduces the efficiency of the process or results in wastage of pollen.
- ✓ The use of the robotics system at a large/field-scale level remains limited.

Plan Bee- A New Approach to Pollination



Fig. 2: Honey Bee Vs Plan Bee Robotic Pollination

This novel concept of pollination has been created by an industrial design student, “Anna Haldewang”, at Savannah College of Art and Design, Georgia. The Plan Bee drone/robot artificially pollinates the flowers on behalf of the bees upon detecting the flower through its ultraviolet camera. It imitates the appearance of honeybees with its black and yellow stripes and facilitates pollination by sucking the

pollen through a port present on the lower side. Thus, it could become an emergency backup to artificially cross-pollinate plants in response to the decline in real bee populations.

Future prospects and conclusion

Considering the future of robotic/automated pollination, accuracy improvement and adaptability to other fruits and vegetables become important. It is vital to include artificial intelligence, machine vision, and depth sensing to an extent in order to enhance flower recognition and identification at the right stage of pollination. Additionally, significant focus should be placed on implementing these intelligent robotic control systems at the field level.

However, along with the development of such systems, there emerges a larger issue regarding the future of farming: whether robots will be able to replace natural pollinators in the future.

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