DEPARTMENT OF AGRICULTURE DEVELOPMENT
& FARMERS' WELFARE, GOVERNMENT OF KERALAM

FARM INFORMATION BUREAU

KERALA KARSHAKAN

THE FIRST ENGLISH FARM JOURNAL FROM THE HOUSE OF KERALA KARSHAKAN

NOVEMBER 2026
VOLUME 14 ISSUE 06

E-JOURNAL



El Niño and Modern Agriculture

Challenges, Risks and Adaptation

INSIDE

KERALAKARSHAKAN

NOVEMBER 2026 • VOLUME 14 • ISSUE 06

Mail editorejournalkkfib@gmail.com Log on to www.fibkerala.gov.in Phone: 0471 2314358

THE FIRST ENGLISH FARM JOURNAL FROM THE HOUSE OF KERALA KARSHAKAN

CHIEF EDITOR Sheeba George K EDITOR Anita C S ASSISTANT EDITORS Dr. Anju V S, Al Unais A J

COVER DESIGN AND LAYOUT Deepak Mouthatil

FARM INFORMATION BUREAU
ADVISORY COMMITTEE

CHAIRMAN
MINHAJ ALAM IAS
Principal Secretary & Agriculture Production Commissioner

MEMBERS
ARJUN PANDIAN IAS
Director of Agriculture Department of Agriculture Development & Farmers' Welfare

SABIN SAMEED IAS
Director (I&PRD)

DR K SINDHU
Director(iC) (Animal Husbandry)

SALINI GOPINATH
Director, Dairy Department

STATION DIRECTOR
All India Radio

DIRECTOR
Doordarshan, Thiruvananthapuram

C RADHAKRISHNAN
Chamravattom, Tirur, Malappuram.

BENYAMIN
Njettoor, Kulanada, Pandalam

BAIJU CHANDRAN
Niravu Jaisree Buldings, Thycaud PO, Thiruvananthapuram -14

DR. KHADEEJA MUMTAZ
Chevarambalam, Kozhikkode

ALANKODE LEELA KRISHNAN
Alankode PO, Malappuram - 679591

MURALEEDARAN THAZHAKARA
Pothannur, Krishnakripa, Thazhakara PO Mavelikara, Alappuzha

KARIYAM RAVI
115 Journalist Coloney, NCC Nagar, Peroorkada, Thiruvananthapuram

DR. SAJEED A.
Vilayil Veedu, Chanthavila Sainik School PO, Kazhakootom, Thiruvananthapuram

SURESH MUTHUKULAM
Sarayoo, Bapuji Nagar, Pongumoodu Medical College P.O, Trivandrum - 695011

CONVENOR
SHEEBA GEORGE K

COVERSTORY

4 EL NIÑO, AGRICULTURAL MARKET VOLATILITY AND FISCAL STRESS: EMERGING CHALLENGES FOR KERALA

6 EL NIÑO 2026–27 WHAT IT MEANS FOR INDIAN AGRICULTURE

11 IMPACT OF EL NINO ON INDIA'S LIVESTOCK SECTOR AND STRATEGIES FOR CLIMATE RESILIENCE

18 CASSAVA AND CLIMATE CHANGE ADAPTING FOR A RESILIENT FUTURE

SEAWEED FARMING

25 SEAWEEDFARMING GREEN GOLD FROM THE BLUE SEA

MARKET INTELLIGENCE

32 EMERGING TECHNOLOGIES TRANSFORMING MARKET INTELLIGENCE FOR FARMERS

KITCHEN GARDEN

37 POINTED GOURD AN UNDERUTILIZED VEGETABLE WITH HIGH NUTRITIONAL SIGNIFICANCE

SCIENCE PLUS

40 FROM RED TO BLUE HOW BREEDING IS CHANGING TOMATO COLOURS

ENVIRONMENT

44 POLICIES OF POLLUTION

Articles for Kerala Karshakan e-journal should be certified by head of the institution concerned stating that the article is original and has not been published anywhere. Reference should also be included wherever relevant.

EL NIÑO AND MODERN AGRICULTURE: CHALLENGES, RISKS AND ADAPTATION



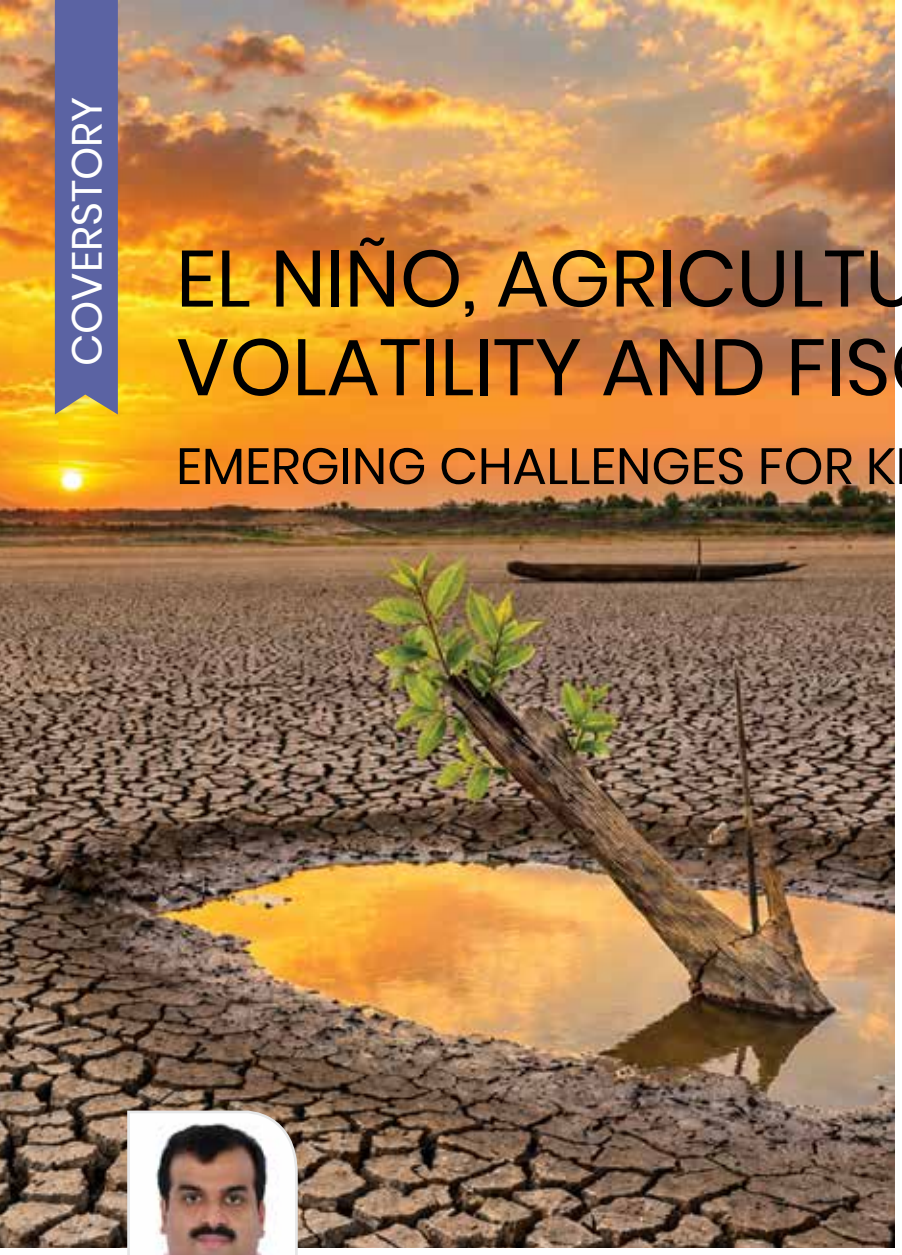
Agriculture is entering a period of significant change, shaped by climate variability, emerging technologies and the need for sustainable production. Farmers must increasingly adapt to changing weather patterns, use natural resources efficiently and identify new opportunities to improve their income. Scientific knowledge and innovative farming practices are essential to address these challenges and building a resilient agricultural sector.

The developing El Niño phenomenon of 2026–27 highlights the urgent need for climate preparedness and timely agricultural advisories. The adoption of climate-resilient crops and climate-smart agricultural practices offers practical and effective strategies to mitigate climate risks, sustain farm productivity and enhance farmers' income. Informed crop selection, efficient resource management, effective market interventions and the adoption of good agricultural practices are essential to helping the farming community withstand the challenges posed by El Niño and other climate-related uncertainties.

This issue also brings into focus important developments and emerging opportunities across various sectors of agriculture. It features advances in tomato breeding, cultivation practices for nutritious crops such as pointed gourd, and the potential of seaweed farming to generate additional livelihood opportunities for coastal communities. The issue further explores plant health management and pollution control measures, emphasising the importance of protecting agricultural resources and preserving environmental quality.

The articles in this issue of Kerala Karshakan E-Journal offer diverse insights into the challenges, innovations and opportunities shaping the future of agriculture. The sustainability of the agricultural sector depends on bridging the gap between scientific research and field-level application, while promoting responsible resource utilisation, technological innovation and market-oriented farming practices.

As we navigate the uncertainties of climate change, embracing innovation, strengthening climate resilience and adopting sustainable agricultural approaches will be crucial to building a productive and prosperous farming sector. Through the collective efforts of researchers, policymakers, extension professionals and farmers, we can safeguard agricultural resources, strengthen farmers' livelihoods and ensure a resilient and sustainable agricultural future for generations to come.



EL NIÑO, AGRICULTURAL MARKET VOLATILITY AND FISCAL STRESS:

EMERGING CHALLENGES FOR KERALA

S.S. Nagesh

Chief, Agriculture Division, Kerala State Planning Board

The chapter on Agriculture in the World Bank's CMO-October-2026 suggests that the effects of El Niño could be deeper and more long-lasting than previously anticipated. With indications that this may be one of the strongest El Niño events in recent decades, global agricultural markets are entering a period of heightened uncertainty.

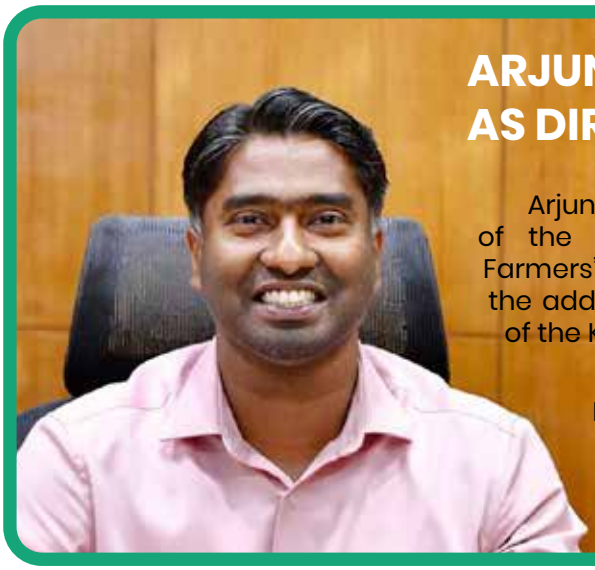
Grains, particularly wheat, have experienced sharp price increases, while food prices are expected to remain elevated through 2027. Wheat, rice, maize, and vegetable oils continue to face upward pressure due to production shortfalls, climate-related disruptions, and persistent supply uncertainties. Global rice production is projected to decline for the first time in a decade, while tightening oilseed and feed markets are likely to further increase food and input costs.

These developments have important implications for public finances. National and state budgets may face increasing pressure as governments strive to protect consumers and farmers from rising prices. Policymakers will need to balance food security, farmer welfare, and fiscal sustainability in an increasingly volatile global environment.

Recognising these emerging challenges, the Hon'ble Minister for Agriculture, Government of Kerala, recently convened a stakeholder consultation to assess the likely impacts and prepare appropriate responses. A key area of focus is expanding the area under assured irrigation by leveraging resources from multiple schemes and institutions.

While higher commodity prices may initially benefit some farmers, rising costs of fertilizers, feed, fuel, labour, and irrigation could erode these gains. If input costs rise faster than output prices, farm incomes may not improve proportionately.

For smaller states such as Kerala, the consequences extend well beyond inflation. Higher food prices can increase welfare expenditure, farmer-support programmes may require better resources with participation of private sector, and the dairy and livestock sectors could face significant stress from escalating feed costs. Public institutions supplying subsidized seeds, fertilizers, and planting materials may also encounter higher operational expenses. Together, these pressures could expand subsidy commitments and reduce fiscal space for long-term investments in agricultural infrastructure, innovation, and climate resilience.



ARJUN PANDIAN IAS TAKES CHARGE AS DIRECTOR OF AGRICULTURE

Arjun Pandian IAS has assumed charge as the Director of the Department of Agriculture Development and Farmers' Welfare, Kerala. He has also been entrusted with the additional responsibility of Additional Project Director of the KERA Project.

A 2017-batch IAS officer of the Kerala cadre, Arjun Pandian previously served as the District Collector of Kasaragod. He has also held key administrative positions, including District Collector of Thrissur and Assistant Collector of Kannur.

The challenge before policymakers is therefore not merely to manage the immediate effects of higher prices, but to build a more resilient agricultural system capable of withstanding climate shocks while ensuring food security, farmer prosperity, and fiscal prudence.

CLIMATE CHANGE RESPONSE: STATE-LEVEL MONITORING UNIT TO BE ESTABLISHED

The Kerala Government has decided to establish a state-level monitoring unit to coordinate measures to address the impact of climate change, including El Niño, on agriculture. The proposed unit will bring together various government departments, the State Disaster Management Authority and NABARD. The decision was taken at a ministerial meeting chaired by Agriculture Minister T. Siddique at the Legislative Assembly Banquet Hall. The meeting also resolved to formulate short- and long-term action plans and coordinate available funding sources for effective implementation.



Agriculture Minister T. Siddique chairs the ministerial meeting at the Legislative Assembly Banquet Hall to discuss coordinated measures to address the impact of climate change on agriculture. Water Resources Minister Mons Joseph, Revenue Minister A. P. Anilkumar and Agriculture Director Arjun Pandyan IAS are among those present.

The integrated action plan will prioritise water conservation, restoration of canals and ponds, improved water management systems, drip irrigation, rainwater harvesting and water storage wells. Measures to increase green cover and maintain soil moisture will also be included. District-level meetings under the leadership of District Collectors will assess local challenges and formulate suitable interventions. Panchayat-level plans will also be prepared to ensure effective implementation.

Kuttanad will receive special attention, with the possibility of a dedicated mission to address its climate-related challenges. Agriculture Minister T. Siddique called for coordinated action among departments and effective utilisation of available resources. Water Resources Minister Mons Joseph and Revenue Minister A. P. Anilkumar emphasised the need for stronger interdepartmental coordination to address issues such as flood prevention, drainage, water management and bund protection.

EL NIÑO 2026–27

WHAT IT MEANS FOR INDIAN AGRICULTURE

EL NIÑO IN A WARMER WORLD IS BECOMING AN AGRICULTURAL CHALLENGE—NOT SIMPLY A RAINFALL STORY



Dr. G. Byju

Director, ICAR-Central Tuber Crops Research Institute (CTCRI), Sreekariyam P.O., Thiruvananthapuram 697017, Kerala

THE PACIFIC IS SENDING AN AGRICULTURAL WARNING

The tropical Pacific is warming again. The developing El Niño of 2026–27 matters not simply because another El Niño is occurring, but because it is occurring against a substantially warmer climatic background. For agriculture, this combination raises an important question: how will changes in rainfall interact with higher temperatures, soil-moisture depletion and crop water demand?

The World Meteorological Organization (WMO) says El Niño is established and is expected to strengthen, potentially reaching very strong intensity towards the end of 2026, with the event likely to persist into early 2027. The important point for agriculture is not to translate this forecast directly into a prediction of drought. Rather, it is to use the information as an early-warning signal and prepare for a range of possible regional outcomes.



El Niño begins in the Pacific, but its agricultural consequences can travel thousands of kilometres through changes in atmospheric circulation, rainfall and temperature. For India, the response is further modified by the Indian Ocean Dipole (IOD), monsoon dynamics and regional land–atmosphere processes.

WHAT EXACTLY IS EL NIÑO?

El Niño is the warm phase of the El Niño–Southern Oscillation (ENSO), a naturally recurring climate phenomenon centred on the tropical Pacific Ocean. During an El Niño, surface waters in the central and eastern equatorial Pacific become unusually warm. This ocean warming changes atmospheric circulation, which in turn alters rainfall and temperature patterns in distant parts of the world.

El Niño does not mean drought everywhere. Some regions experience reduced rainfall and heat, while others may receive excessive rainfall and flooding. Its influence can extend to agriculture, fisheries, water resources and energy demand.

El Niño episodes recur irregularly, typically at intervals of about two to seven years. Their effects also differ from one event to another because ENSO interacts with other climate drivers. For agricultural planning, therefore, the useful question is not simply whether an El Niño exists, but what its likely regional expression will be.

EL NIÑO AND THE INDIAN MONSOON: A WARNING, NOT A VERDICT

India has historically experienced a relationship between El Niño and the southwest monsoon. Many El Niño years have been associated with weaker monsoon rainfall. However, this relationship is not deterministic. The Indian monsoon is governed by interactions among the Pacific Ocean, Indian Ocean, land–atmosphere processes and several other climatic influences.

The Indian Ocean Dipole is particularly important. A positive IOD can modify the influence of El Niño on Indian rainfall. Consequently, Pacific Ocean temperatures alone cannot provide a complete picture of the agricultural season. For farmers and agricultural planners, this distinction is crucial. El Niño should be treated as a risk signal rather than a direct forecast of drought. Seasonal forecasts must be translated into regional and district-level assessments before crop decisions are made.

WHY EL NIÑO IS DIFFERENT IN A WARMER WORLD

The most important change in the agricultural context is the temperature background. El Niño is a natural climate fluctuation, while global warming is changing the baseline on which that fluctuation occurs. A warmer atmosphere can increase evaporative demand—the amount of water that the atmosphere can draw from soil, crops and other surfaces. Consequently, even a moderate reduction in rainfall can produce considerable soil-moisture stress when temperatures are high.

A simple way to express the agricultural problem is:

Rainfall deficit + higher temperature + greater evaporative demand = greater soil-moisture stress.

This is why rainfall alone is becoming an inadequate indicator of agricultural drought. A crop responds not merely to how much rain falls, but to when it falls, how much water remains in the root zone, how rapidly water is lost through evapotranspiration, and how these conditions coincide with critical crop growth stages.

FROM RAINFALL FORECASTING TO IMPACT FORECASTING

Agricultural planning needs to move beyond the question, "Will rainfall be below normal?" The more useful questions are: What will happen to soil moisture? Which crops will face water stress? When will the stress occur? How much irrigation will be required? Which varieties and planting dates can reduce the risk?

This requires integrating rainfall forecasts with temperature, evapotranspiration, soil moisture, groundwater, reservoir storage and crop water requirements.

The chain should therefore be:

Climate forecast → regional climate assessment → soil-moisture and water assessment → crop-impact assessment → district contingency plan → farmer advisory → field-level action.

A forecast that does not reach the farmer has limited value. A forecast that reaches the farmer without an actionable contingency plan is only marginally better.

HOW EL NIÑO CAN AFFECT AGRICULTURE

The agricultural pathway is relatively straightforward:

Ocean warming → atmospheric circulation → rainfall and temperature → soil moisture → crop growth → yield → prices → farm income → food security.

But the magnitude of the impact depends strongly on crop, location, soil, irrigation and management. For rice, the timing and distribution of rainfall can be as important as seasonal rainfall totals. A season with near-normal accumulated rainfall can still cause substantial yield loss if prolonged dry spells occur during establishment, flowering or grain filling. Maize is particularly sensitive to heat and moisture stress during reproductive stages. Pulses and oilseeds in rainfed systems may be affected by delayed rainfall, prolonged dry spells and high temperature. Horticultural crops can experience heat stress, poor flowering and fruit set, changes in quality and shifts in pest and disease dynamics.

Livestock systems are also exposed through higher water requirements, heat stress and changes in fodder availability. Therefore, the agricultural consequences of El Niño should not be measured only in tonnes of production lost. They should also be assessed through irrigation demand, soil-moisture deficits, livestock productivity, farm income, food prices and nutritional security.

NOT ALL CROPS WILL RESPOND IN THE SAME WAY

One of the weaknesses of broad climate discussions is that they sometimes treat agriculture as a single system. In reality, crop responses differ greatly. Rainfed crops are generally more exposed to rainfall variability than well-irrigated crops, but irrigation itself may become constrained when reservoirs, groundwater and surface-water availability decline. Soil type also matters: crops grown on shallow or low-water-holding soils can experience stress much earlier than crops on deeper soils.

Crop duration is another important factor. Short-duration cultivars can sometimes escape late-season moisture stress. Conversely, changes in planting date can expose flowering or grain filling to periods of extreme heat. This makes crop and variety choice an important component of climate adaptation. Breeding for drought and heat tolerance, improving water-use efficiency and developing varieties suited to changing growing seasons should therefore accompany conventional yield improvement.

TROPICAL ROOT AND TUBER CROPS: A CLIMATE-RESILIENT COMPONENT

Tropical root and tuber crops such as cassava, sweet potato, yams, taro and elephant foot yam deserve particular attention in discussions on agricultural resilience. Compared with crops such as rice and wheat, many tuber crops are relatively more resilient to drought and heat stress, with generally lower yield losses under moderate climatic stress. Their flexibility and suitability for intercropping in orchards and other diversified farming systems further enhance their value.

This does not mean that tuber crops are immune to climate stress. Prolonged moisture stress, high temperatures, pests and diseases, planting-material constraints and changes in rainfall distribution can affect productivity. Their strategic value lies in their relative resilience and ability to diversify production, reducing dependence on a narrow range of crops.



Improved varieties, healthy planting material, short-duration cultivars, soil-moisture conservation, efficient nutrient and water management, rainwater harvesting and value addition can further strengthen their role. For vegetatively propagated tuber crops, timely multiplication and distribution of healthy planting material should be an important component of climate contingency planning.

THE HIDDEN THREAT: ATMOSPHERIC EVAPORATIVE DEMAND

One of the most important scientific developments in drought assessment is the growing recognition that drought cannot be understood from rainfall alone. When temperatures rise, the atmosphere can demand more water from crops and soils. If rainfall does not compensate for this increased atmospheric demand, soil moisture declines faster. Plants may therefore experience water stress even when rainfall deficits appear modest.

This has major implications for agricultural monitoring. Future drought early-warning systems should combine rainfall with temperature, evapotranspiration, soil moisture, groundwater, reservoir storage, crop stage and crop water requirement. In other words, agriculture needs to move from weather forecasting towards impact forecasting.

EL NIÑO AS A STRESS TEST FOR INDIAN AGRICULTURE

Every major climate event exposes weaknesses that may remain hidden during normal years. El Niño 2026–27 should therefore be treated as a stress test for India's agricultural resilience. The first requirement is anticipation. Seasonal forecasts provide valuable lead time, but that lead time becomes useful only when translated into decisions. Agricultural institutions should prepare district-specific scenarios based on likely rainfall and temperature conditions and update them as forecasts improve.

The objective should be to answer practical questions: Should sowing dates be adjusted? Which crops and varieties should be promoted? Where should irrigation water be conserved? What planting material should be multiplied in advance? Which livestock systems are most exposed? Where are contingency markets and storage required?

This requires close coordination among meteorological agencies, ICAR institutes, agricultural universities, Krishi Vigyan Kendras, state agriculture departments, water-resource agencies, insurance providers, farmer organisations and markets.

WHAT SHOULD INSTITUTIONS AND GOVERNMENTS DO?

Preparedness should begin before the climatic

WHAT SHOULD FARMERS DO?

At farm level, several measures can reduce exposure to El Niño-related stress:

- **Water:** harvest rainwater, maintain farm ponds, adopt micro-irrigation and schedule irrigation according to crop need.
- **Soil:** use mulching, residue management, organic-matter improvement and other soil-moisture conservation practices.
- **Crops:** consider drought- and heat-tolerant varieties, short-duration cultivars and diversified cropping systems where locally appropriate.
- **Planting dates:** use seasonal advisories to avoid exposing sensitive crop stages to anticipated dry or hot periods.
- **Nutrients:** adopt efficient and site-specific nutrient management to avoid unnecessary losses and support crop resilience.
- **Planting material:** maintain access to quality seed and healthy vegetative planting material.
- **Risk management:** use weather advisories, crop insurance and locally relevant contingency plans.
- **Markets:** strengthen storage, processing and value addition so that temporary production shocks do not translate immediately into severe income losses.



stress becomes visible in fields. First, seasonal climate forecasts should be converted into district-level agricultural advisories. Second, crop contingency plans should be updated before the season and linked to clear triggers for action. Third, seed and planting-material systems should be prepared for rapid replacement or diversification when conditions change.

Water-resource planning is equally important. Reservoir and groundwater status should be considered alongside seasonal rainfall forecasts. Irrigation scheduling and water allocation may need to be adjusted where prolonged dry spells are anticipated.

Agricultural extension systems should strengthen last-mile communication through KVKs, farmer organisations, digital advisories and local-language messages. Insurance and credit systems should also be prepared for weather-related disruptions.

Finally, monitoring should continue through the season. The most useful early-warning system is not one that predicts a hazard once, but one that continuously links changing climate conditions with crop-stage-specific risks and recommended actions.

AGRICULTURE AND HUMAN HEALTH: ONE CONNECTED SYSTEM

The agricultural consequences of El Niño can also affect human health. Reduced agricultural production can influence food availability, prices and nutritional security, while higher temperatures increase heat stress, particularly among agricultural workers. Water scarcity and extreme heat can place additional pressure on rural livelihoods and health services. Protecting agricultural production during an El Niño event is therefore not only an economic priority but also an important component of food and nutritional security.

FROM PRODUCTIVITY TO RESILIENCE

India's agricultural transformation has historically focused strongly on raising productivity and achieving food security. The challenge is now broader. Agriculture must remain productive under increasing climatic variability.

This means breeding for resilience along with yield; conserving water alongside expanding irrigation; improving soil health alongside fertilizer use; diversifying crops alongside intensification; and strengthening local food systems alongside national and global markets.

The objective is not to eliminate climate variability. That is impossible. The objective is to reduce the sensitivity of agriculture and rural livelihoods to that variability. El Niño 2026–27 should therefore be seen not merely as another climate event to be endured, but as an opportunity to test whether our agricultural systems can anticipate stress, adapt before losses occur and recover rapidly afterwards.

THE PACIFIC GIVES THE WARNING

El Niño begins in the tropical Pacific, but its agricultural consequences can reach an Indian farmer's field, irrigation reservoir, livestock system and food market. Its effects will be modified by the Indian Ocean Dipole, the monsoon, regional climate processes and local vulnerability.

No single climate index can tell us exactly what will happen in every district. But the scientific message is clear: a naturally occurring climate fluctuation is now interacting with a warmer baseline.

The challenge before Indian agriculture is therefore not merely to predict the next El Niño. It is to build farming systems capable of absorbing climate shocks without allowing them to become livelihood and food-security crises.

The Pacific gives the warning. **Preparedness will determine the outcome in the field.

IMPACT OF EL NINO ON INDIA'S LIVESTOCK SECTOR

AND STRATEGIES FOR CLIMATE RESILIENCE



Dr S. Harikumar

Professor,
Centre for Animal Adaptation to Environment and Climate Change Studies (CAADECCS)
Kerala Veterinary and Animal Sciences University
Mannuthy, Thrissur, Keralam-680 651

A change in the temperature of the Pacific Ocean, thousands of kilometers away from India, can influence the monsoon, agricultural production and the livelihoods of millions of farmers. This phenomenon, known as El Nino, can have far reaching consequences for India's livestock sector by affecting feed and fodder availability, water resources, animal health and milk production. Understanding its potential impacts and adopting timely adaptation strategies are essential to safeguard livestock productivity, protect farmers' livelihoods and strengthen the resilience of the livestock sector to climate variability.

WHAT IS EL NINO?

Nowadays, the term El Nino is mentioned more frequently in weather forecasts and news reports. It refers to an important climate phenomenon arising from changes in the interaction between the Pacific Ocean and the atmosphere, particularly variations in trade winds, sea-surface temperatures and the movement of warm ocean water. These changes influence weather patterns across the globe, potentially contributing to floods, droughts, heat waves

and storms in different regions.

The El Nino is only one of the three phases of the natural phenomenon called ENSO (El Nino–Southern Oscillation) - a naturally occurring climate phenomenon in which surface waters across the central and eastern equatorial Pacific Ocean become unusually warm, disrupting weather patterns around the world. Changes in atmospheric pressure, trade winds, ocean surface temperatures and ocean circulation across the tropical Pacific form the basis of ENSO. This coupled ocean–atmosphere phenomenon influences the distribution of heat and moisture, thereby affecting weather patterns across the globe. ENSO influences global weather patterns, including rainfall, temperature, droughts, floods and the occurrence of extreme weather events. Therefore, these phases are important for agriculture, livestock production, water resource management and climate change preparedness.

El Nino was first recognized in 1600s by Peruvian fishermen and sailors who noticed every few years warmer ocean waters would appear, disrupting fisheries and bringing intense rainfall and storms off the coast of South America at the end of the year around Christmas. Though ENSO is a single climate phenomenon, it has three phases. The two opposite phases are El Nino and La Nina, with ENSO-neutral condition in between. (El Nino is a Spanish word for little boy or Christ child and La Nina means little girl). El Nino events typically last around 9–12 months, although some may persist for 18 months or longer. La Nina events can also vary in duration and may persist for 2-3 years in some cases. It has been operating for thousands of years, long before human industrialization or the burning of fossil fuels began. But human induced climate change is causing disturbances in the normal oscillation pattern and the oscillation cycle becomes increasingly erratic and violent. Current scientific consensus suggests that rising greenhouse gases are altering the cycle in two major ways:

- More extreme events: The frequency of Super El Nino and extreme La Nina has increased.
- Increased volatility: The swings between severe droughts and torrential floods are becoming much more intense, rapid, and destructive.

EL NINO

El Nino is characterized by unusually warm ocean surface temperatures in the central and eastern tropical Pacific Ocean off the western coast of South American continent. Trade winds play an important role in ENSO formation. Trade winds are steady winds that blow from the subtropical high pressure belts towards the equatorial low pressure belt. They are mainly caused by differences in atmospheric pressure and the rotation of the Earth. When trade winds weaken due to natural fluctuations in the tropical Pacific atmosphere, warm surface water that is normally pushed towards the western Pacific can move eastward towards the central and eastern equatorial Pacific, contributing to the development of El Nino. As a result, rainfall shifts toward South America and parts of Southeast Asia (Indonesia, Philippines) and Northern Australia experience the most direct and extreme drought conditions during El Nino. El Nino weakens the southwest monsoon in India by altering atmospheric pressure and pushing moisture away from the Indian subcontinent, leading to delayed monsoon onsets, prolonged dry spells, and an overall deficit in rainfall.

LA NINA IS THE OPPOSITE PHASE OF EL NINO. IT REPRESENTS A PERIOD OF UNUSUAL COOLING OF OCEAN SURFACE TEMPERATURES IN THE CENTRAL AND EASTERN TROPICAL PACIFIC OCEAN, OFF THE WESTERN COAST OF SOUTH AMERICA.

LA NINA

La Nina is the opposite phase of El Nino. It represents a period of unusual cooling of ocean surface temperatures in the central and eastern tropical Pacific Ocean, off the western coast of South America. The strong trade winds push warm surface water toward Asia and Australia, allowing cold, nutrient rich water to rise up from the deep ocean along the coast of South America. Over Indonesia, rainfall tends to increase while rainfall decreases over the central tropical Pacific Ocean. In India, La Nina is generally associated with normal to above-normal southwest monsoon rainfall, which can benefit agriculture by improving soil moisture and water availability.

ENSO NEUTRAL PHASE

This is neither El Nino nor La Nina. The ocean surface temperature often remains close to average with a fluctuation less than 0.5°C. The average normal ocean surface temperature across the entire Pacific is approximately 16.9°C and varies significantly by latitude and longitude.

WHAT IS SUPER EL NINO OR VERY STRONG EL NINO?

El Nino is classified as Super or Very strong based on the temperature of the ocean at a particular region off the coast of South America. The warmer the ocean water, the stronger the El Nino. When the water is more than 2oC warmer than the long term average, it is called Super or Very strong El Nino. According to the World Meteorological Organization (WMO) the ongoing 2026 El Nino is tracking to be one of the most extreme events on record, with peak temperatures in the Pacific epicenter expected to reach up to 3.7°C- 3.8°C above normal during October–December, 2026.

WHY IS THE EL NINO OF 2026-2027 RAISING CONCERNS?

Expert forecasts indicate that the ongoing El Nino event is continuing to intensify and could become one of the strongest on record. It is expected to reach its peak around December 2026, with its effects potentially continuing into 2027 and beyond in some regions. These effects may influence agricultural production cycles, including crop yields and the availability of feed and fodder for livestock.

IMPACT OF EL NINO ON LIVESTOCK SECTOR OF INDIA

El Nino can have a severe impact on agriculture, livestock farming, water resources, and overall livelihood of rural India. El Nino can affect India's livestock sector by altering monsoon rainfall patterns, increasing the risk of heat stress and reducing the availability of feed, fodder and water. These changes may reduce milk production, impair reproductive performance, increase animal health risks and raise livestock production costs, particularly in drought prone regions. The resulting decline in productivity and increase in input costs may affect farmers' incomes and place upward pressure on milk prices, although the severity of these impacts varies across regions and ENSO events.

CHANGE IN THE WEATHER PATTERN

Indian agriculture is highly dependent on the southwest monsoon, which provides almost 75% of the country's annual rainfall. During pronounced El Nino events, the monsoon is often weakened, leading to reduced rainfall and drought in many parts of the country. Extreme weather events, such as heat waves, floods and landslides, can reduce the nutritional quality of grasses and shorten crop growth cycles. As a result, agricultural production may decline significantly, threatening the food security of millions of people and adversely affecting livestock farming. Since agriculture is closely linked to the rural economy, disruptions in the sector can have far reaching consequences, particularly for rural livelihoods and farmers' incomes.

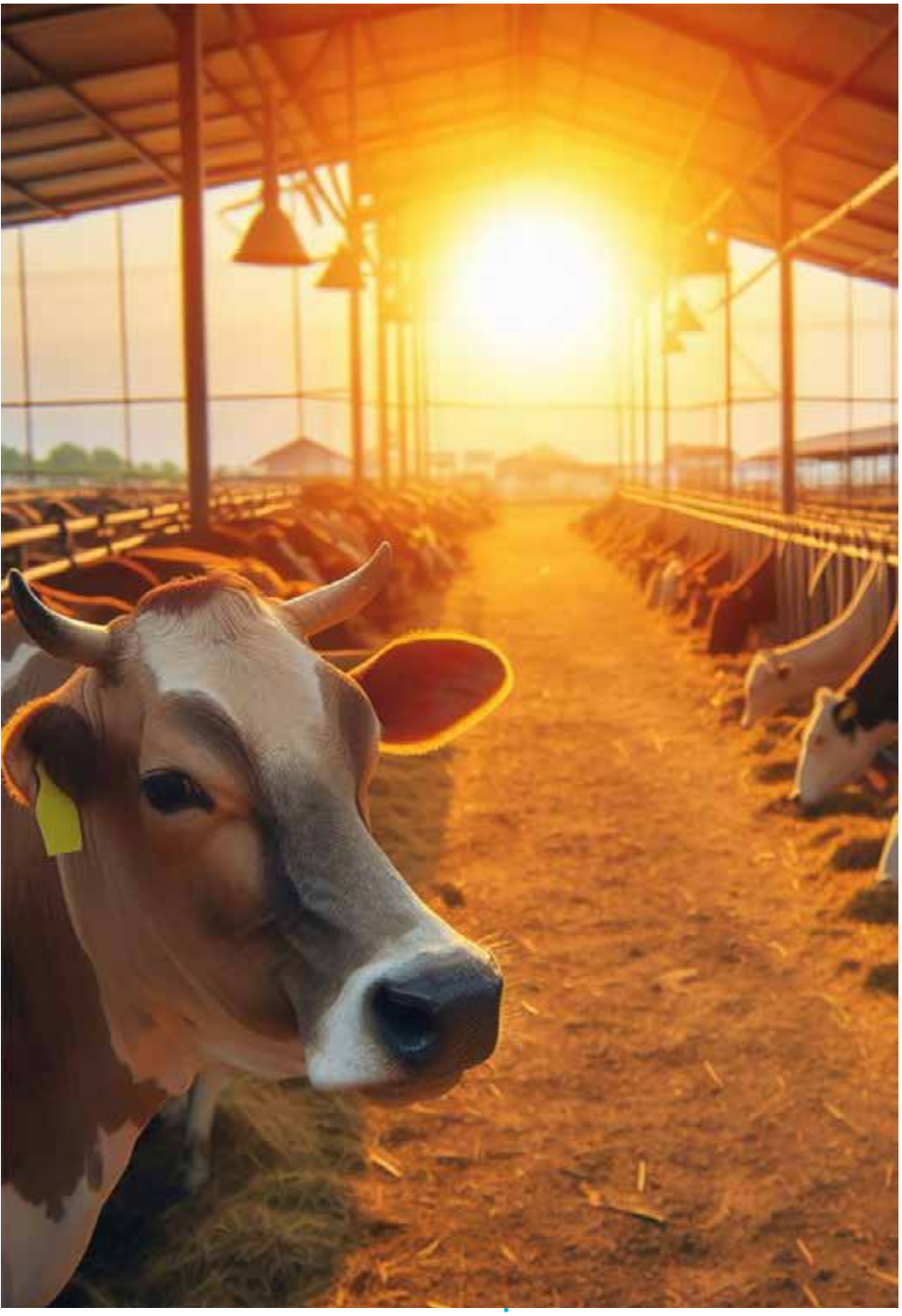
INDIAN AGRICULTURE IS HIGHLY DEPENDENT ON THE SOUTHWEST MONSOON, WHICH PROVIDES ALMOST 75% OF THE COUNTRY'S ANNUAL RAINFALL. DURING PRONOUNCED EL NINO EVENTS, THE MONSOON IS OFTEN WEAKENED, LEADING TO REDUCED RAINFALL AND DROUGHT IN MANY PARTS OF THE COUNTRY.

EXHAUSTION OF WATER RESOURCES

Reduced monsoon rainfall can lead to severe water shortages in rural India. Many rural communities depend primarily on surface water sources, such as rivers and reservoirs, for domestic and agricultural activities. Changes in monsoon rainfall may also reduce groundwater recharge, causing both surface water and groundwater resources to be depleted at an alarming rate. This is a serious concern in India, where agriculture accounts for approximately 80–90% of total freshwater withdrawals, substantially exceeding the global average of about 70%.

THERMAL STRESS ON LIVESTOCK

Increase in ambient temperature makes it difficult for livestock species to dissipate body heat, leading to severe thermal stress. High yielding animals are highly prone to thermal stress. The physiological responses of animals to thermal stress can adversely affect their performance. Furthermore, interventions to alleviate



thermal stress in livestock increase farmers' financial burden and may lead to economic losses.

REDUCTION IN PRODUCTION AND PRODUCTIVITY

Reduced feed intake and the diversion of energy towards thermoregulatory mechanisms can lead to a decline in milk production in dairy animals. A reduction in both the quantity and quality of milk can have significant economic consequences and raise concerns about food security. A 1°C rise in ambient temperature may result in a reduction of 1.5–2 litres of milk per animal per day. A recent study projected that rising temperatures could reduce milk production by 25% in the arid and semi-arid regions of India by 2085.

EFFECT ON REPRODUCTION

Changes in temperature and photoperiod can lead to reproductive problems in dairy animals due to hormonal imbalances. Thermal stress negatively affects reproductive performance by altering the expression and duration of oestrus, ovarian follicle size and development, and early embryonic growth. High temperatures combined with high humidity can increase the incidence of silent oestrus and summer anoestrus in buffaloes in India.

SHORTAGE OF FEED AND FODDER

According to the Indian Council of Agricultural Research (ICAR), India faces a deficit of approximately 35.6% in green fodder and 11% in dry fodder. This situation may be further aggravated by erratic monsoon rainfall and prolonged drought spells, which can reduce agricultural production and, in turn, affect the availability of crop residues for livestock. Traditional village grazing lands have declined by nearly 50%, adversely affecting smallholder dairy farmers who depend on low cost grazing systems. The continuing effects of El Nino may further exacerbate fodder shortages, posing additional challenges to livestock production and the livelihoods of farmers.

PREVALENCE OF DISEASES

Climate change can significantly influence the emergence and spread of livestock diseases in India. Changes in environmental conditions can affect disease patterns, potentially increasing the incidence of parasitic and viral diseases. Higher ambient temperatures and relative humidity can influence the survival, development and activity of disease vectors,

thereby increasing the risk of infection among susceptible animals. Temperature directly affects vector survival and the seasonality of pathogen transmission, while rainfall influences the availability of vector breeding habitats and the risk of vector borne disease transmission. Furthermore, heat stress associated with climate change can weaken animals' immune responses, making them more susceptible to infectious diseases.

MARKETING IMPLICATIONS OF MILK

El Nino can put upward pressure on Indian milk prices through heat stress, fodder scarcity and reduced milk supply, particularly when it coincides with deficient monsoon rainfall. Increased input cost of milk production, potentially leading to higher milk and milk product prices.

IMPACT OF EL NINO ON LIVESTOCK SECTOR OF KERALAM

El Niño may affect Keralam's livestock sector through changes in pre-monsoon temperatures, monsoon rainfall, feed and fodder availability, and water resources. Keralam's tropical, humid climate is particularly relevant because high humidity can make it difficult for livestock to dissipate body heat, even when ambient temperatures are not exceptionally high. Reports from Keralam have documented serious livestock related challenges during periods of extreme heat, including reduced milk production, cattle deaths, and shortages of drinking water and green fodder.

HOW TO PROTECT LIVESTOCK FROM EL NINO?

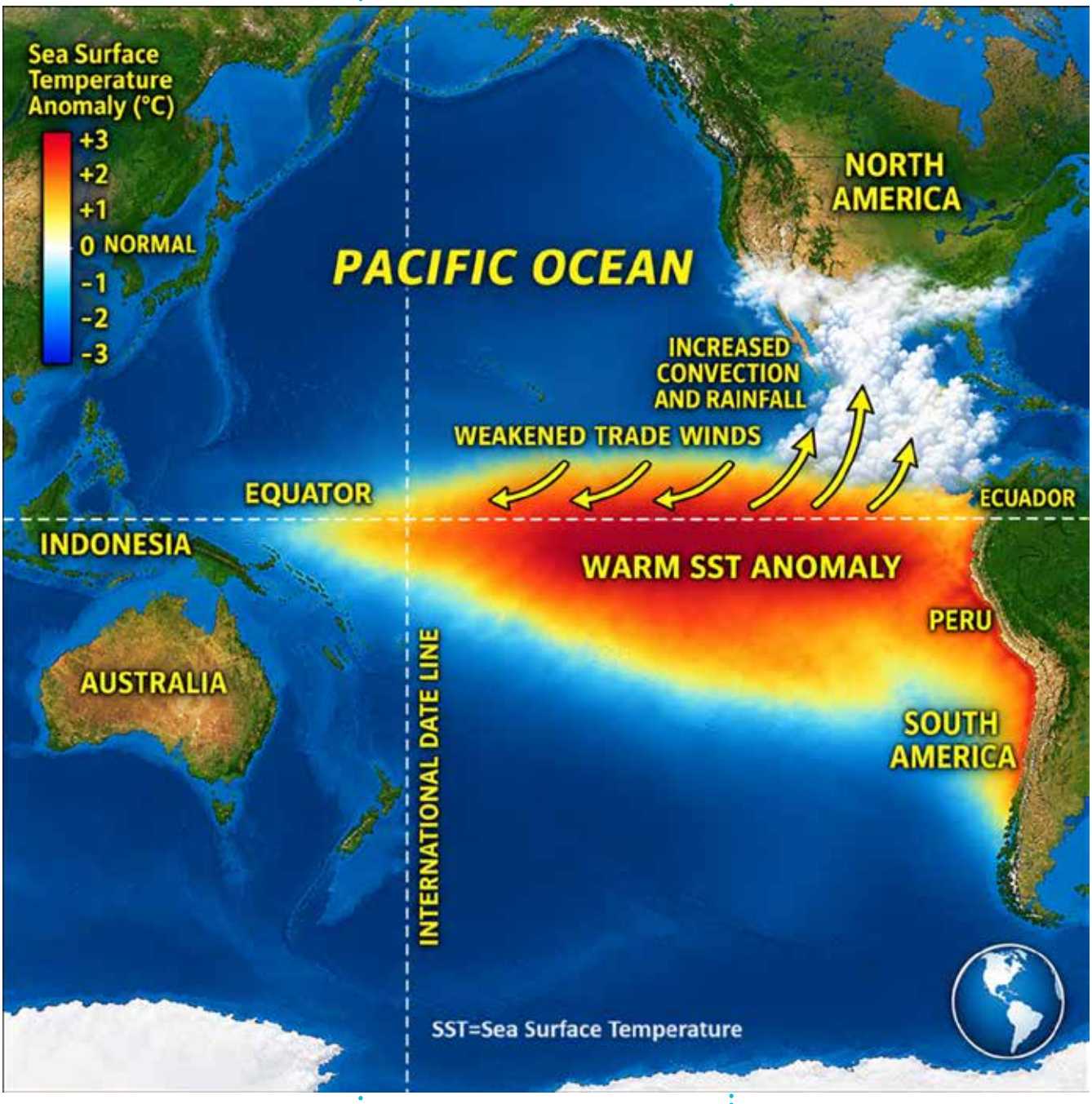
The impacts of El Nino on the livestock sector can be mitigated by adopting a preparedness based approach that focuses on protecting animals from thermal stress, ensuring adequate feed and fodder supplies, conserving water, implementing climate



smart livestock management practices and providing climate based early warnings to farmers.

THERMAL STRESS MANAGEMENT OF ANIMALS

Micro environmental management practices can reduce the effects of thermal stress on animals. Providing shade, adequate ventilation and ad libitum access to clean drinking water can considerably alleviate heat stress. Interventions such as fans, misters and sprinklers can further improve animal comfort. Grazing and exercise should preferably be scheduled during cooler hours, such as early morning and late evening. Ambient temperature and relative humidity should be monitored continuously and appropriate heat-mitigation measures should be implemented based on the Temperature Humidity Index (THI), respiration rate and body temperature. High yielding animals should be given priority to ensure their comfort and welfare and to minimise production losses and reproductive problems.



El Nino events in the Pacific Ocean
(Source: National Oceanic and Atmospheric Administration (NOAA)

ENSURE FEED AND FODDER SECURITY

Feed and green fodder availability can be ensured by identifying and cultivating drought tolerant fodder crops suited to local climatic and soil conditions. Green fodder and crop residues can be effectively preserved and enriched to improve their nutritional quality. It is high time to establish village level fodder banks and emergency feed reserves wherever adequate land and facilities are available. Scientific livestock management practices, including appropriate feeding regimes, are essential to minimise the adverse effects of climate change on livestock.

ENSURE WATER SECURITY

Water and soil conservation measures should be prioritised to ensure the sustained availability of surface water and groundwater. Appropriate measures must be taken to protect existing water bodies from pollution. Rainwater harvesting systems, farm ponds, water storage facilities and check dams across rivers and streams should be developed to enhance rainwater infiltration and groundwater recharge. Local self government bodies should prepare contingency plans to ensure adequate water supplies for drinking and agricultural activities during periods of extreme water scarcity.

ANIMAL HEALTH AND WELFARE

During extreme weather conditions, animals should be closely monitored for signs of heat stress, dehydration and reduced feed intake, and appropriate interventions should be implemented promptly. Effective disease surveillance, along with preventive and therapeutic veterinary services, is essential for maintaining animal health and welfare when environmental conditions are unfavourable.

WATER AND SOIL CONSERVATION MEASURES SHOULD BE PRIORITISED TO ENSURE THE SUSTAINED AVAILABILITY OF SURFACE WATER AND GROUNDWATER. APPROPRIATE MEASURES MUST BE TAKEN TO PROTECT EXISTING WATER BODIES FROM POLLUTION.

WEATHER BASED INSURANCE FOR LIVESTOCK

Weather based livestock insurance is a type of insurance that protects livestock farmers against financial losses associated with adverse weather conditions, such as extreme heat, prolonged dry spells and drought. It is particularly relevant to Keralam, where thermal stress can reduce milk production in dairy cattle and increase the cost of livestock management. Weather based insurance can provide payouts when predefined weather parameters cross agreed thresholds, without requiring an individual assessment of losses for each animal.

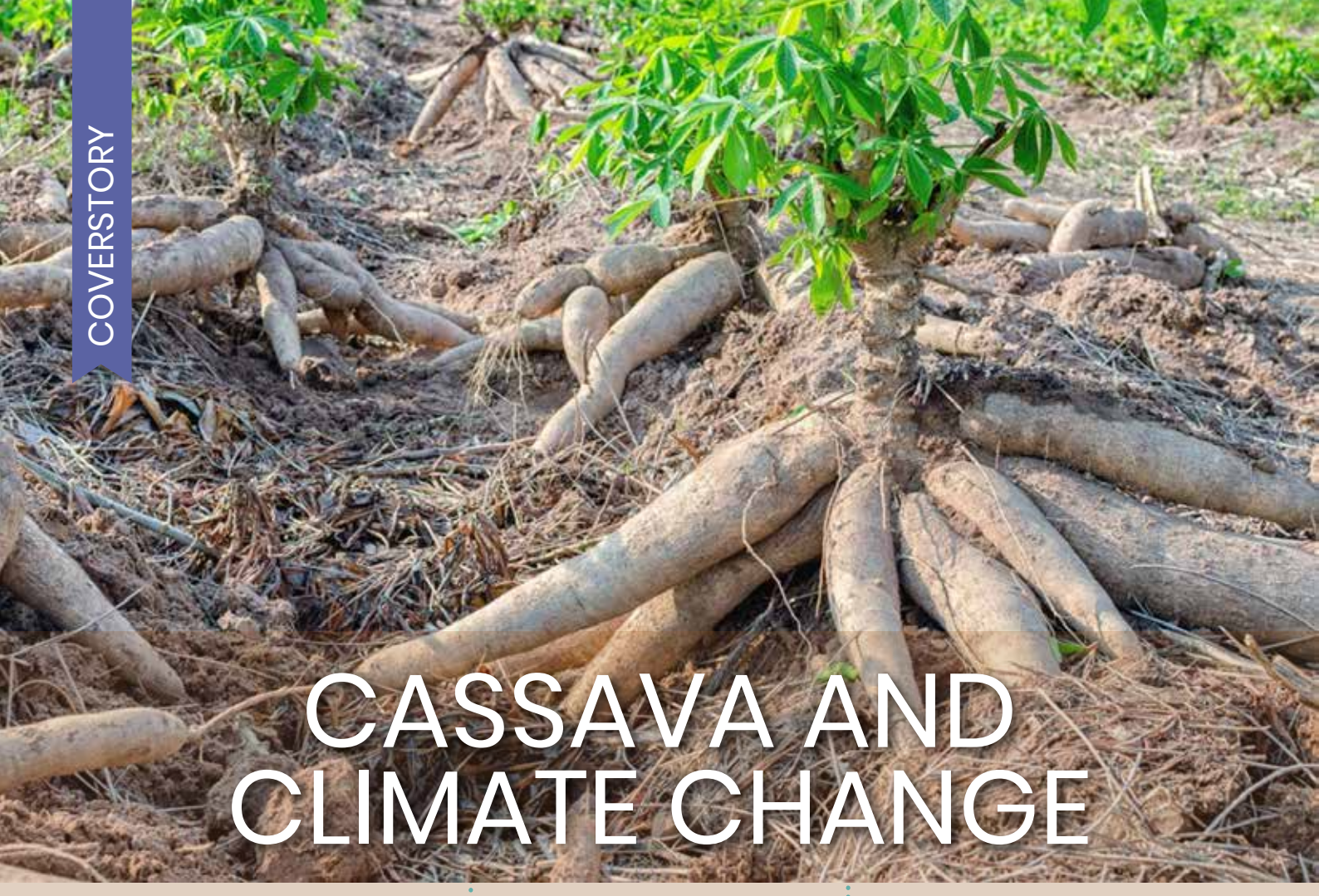
CONCLUSION

El Nino can adversely affect the Indian livestock sector by influencing monsoon rainfall patterns, increasing heat stress and reducing the availability of feed, fodder and water. These conditions may lead to reduced milk production, impaired reproductive performance, increased animal health risks and higher livestock production costs. The resulting decline in productivity and increase in input costs may affect farmers' income and contribute to upward pressure on milk and other livestock product prices. The severity of these impacts varies across regions and depends on local climatic conditions, animal management practices and the availability of resources. Therefore, strengthening climate based early warning systems, fodder and water security, thermal stress management and livestock advisory services is essential to enhance the resilience of India's livestock sector to El Nino events.

References

1. *https://www.fao.org/el-nino/en*
2. *https://wmo.int/themes/el-nino-la-nina-phenomena*
3. *https://www.wfp.org/stories/what-el-nino-how-does-it-affect-hunger-and-how-does-wfp-respond*
4. *https://naas.org.in/Policy%20Papers/Policy%20129.pdf*
5. *https://www.manage.gov.in/publications/eBooks/Climate-smart%20Production%20and%20Processing%20Technology.pdf*

KERALA KARSHAKAN E-JOURNAL NOVEMBER 2026 | 17



CASSAVA AND CLIMATE CHANGE

ADAPTING FOR A RESILIENT FUTURE

D. Jaganathan,
Gauri P Nath,
Sheela Immanuel and
P. Prakash

ICAR-Central Tuber Crops Research Institute,
Sreekariyam, Thiruvananthapuram, Keralam
Corresponding author
email: djaganathtn@gmail.com

INTRODUCTION

Cassava is one of the most important staple crops grown in tropical and subtropical regions of the world. Despite being a perennial, cassava is widely grown as an annual crop in tropical and subtropical areas due to its edible starchy tuberous root. It is mostly eaten cooked but large amounts are processed to produce starch, which is used for industrial, food, and animal feed. Although cassava production is threatened by climate change, farmers and communities may assure the crop's future as a climate-smart crop by using proactive agronomic modifications and community-level resilience techniques. Cassava's climate resilience is largely attributed to its drought tolerance, deep root system, ability to grow under relatively poor soils, and flexible harvesting period. These characteristics help farmers maintain food and income security during irregular rainfall, drought, and other climate-related stresses, although improved varieties and sustainable soil and water management are still needed to strengthen its resilience.

Climate change refers to long-term shifts in temperatures, rainfall and weather patterns, which can be understood through a range of key climatic parameters

that influence agriculture and crop production. Changes in temperature, rainfall, humidity, drought, flooding, soil moisture, carbon dioxide (CO⊠), sunlight, wind patterns, and the frequency of extreme weather events are all indicators of climate change. From shifting weather patterns that threaten food production, to rising sea levels that increase the risk of catastrophic flooding, the impacts of climate change are global in scope and unprecedented in scale. Climate change poses significant challenges to root and tuber crops, requiring robust adaptation strategies to mitigate vulnerabilities.

In the case of cassava, important climate-related factors include rising temperature, changes in the amount and distribution of rainfall, prolonged drought, excess rainfall and flooding, changes in soil moisture, increased salinity in coastal areas, and shifts in pest and disease incidence. These factors can directly affect cassava growth, development, root yield, and quality by altering physiological processes, water availability, nutrient uptake, and the incidence of pests and diseases. Understanding how these climatic stresses interact is essential for identifying vulnerable production conditions and developing suitable adaptation strategies to maintain cassava productivity under changing climatic conditions.

CLIMATE SMART PRACTICES IN CASSAVA

Climate-smart practices (Fig. 1) are farming practices that help farmers adapt to changing climate conditions, reduce climate-related risks, and maintain or increase productivity and income while using natural resources efficiently.

THE IMPORTANT CLIMATE SMART PRACTICES IN CASSAVA ARE DESCRIBED BELOW.

Use of Climate-Resilient/ Smart Varieties: Selection and adoption of climate-resilient cassava varieties is one of the most important strategies for adapting to changing climatic conditions. Varieties with drought tolerance, heat tolerance, disease resistance, shorter duration and stable yield performance under variable environmental conditions should be promoted. The use of locally adapted varieties can help farmers minimize yield losses during periods of drought, excessive rainfall and temperature fluctuations. The important climate-smart cassava varieties developed by ICAR-Central Tuber Crops Research Institute (CTCRI), Thiruvananthapuram, Kerala, are given below. These



Fig. 1. Climate smart practices in cassava

varieties possess desirable characteristics such as drought tolerance, nutrient-use efficiency, CMD resistance, high starch content and tolerance to post-harvest physiological deterioration. Selection of suitable varieties based on agro-climatic conditions can improve productivity, resource-use efficiency and resilience of cassava production under climate variability.

Use of Quality Planting Materials: The use of healthy, disease-free and vigorous stem cuttings is essential for achieving good crop establishment and productivity. Mature stems obtained from healthy plants should be selected for planting, while cuttings showing symptoms of pests, diseases or physiological damage should be avoided. Production and distribution of quality planting material through reliable sources can improve crop establishment and reduce the spread of diseases.

Timely Planting Based on Rainfall: Cassava planting should be adjusted according to the prevailing rainfall pattern rather than following a fixed planting calendar. Planting at the onset of dependable rainfall provides adequate soil moisture for sprouting and early establishment. Weather and seasonal rainfall forecasts can help farmers determine appropriate planting windows and avoid periods of prolonged drought or excessive rainfall immediately after planting.

S**oil and Moisture Conservation:** Soil and moisture conservation practices are important for maintaining cassava productivity under irregular rainfall and prolonged dry periods. Mulching, contour planting, minimum tillage, maintenance of crop residues and incorporation of organic matter can reduce soil erosion and evaporation while improving soil moisture retention. On slopy lands, contour-based cultivation can reduce runoff and loss of fertile topsoil.

Efficient Water Management: Although cassava is relatively drought tolerant, prolonged moisture stress, particularly during crop establishment and important growth



TABLE 1. CLIMATE SMART VARIETIES IN CASSAVA RELEASED BY ICAR-CTCRI

Sl No	Variety	Duration (months)	Yield (t/ha)	Year of release	Important features
1	Sree Manna	9-10	40-50	2025	NPK Use efficient, starch content 20-25 %; Excellent cooking quality Recommended for Kerala
2	Sree Annam	9-10	30-40	2025	NPK Use efficient, starch content 20-25 %; Excellent cooking quality Recommended for Kerala
3	Sree Kaveri	9-10	40-50	2023	Resistant to CMD, high nutrient use efficiency, drought tolerance and starch content 27-28% Recommended for Kerala, Tamil Nadu and Andhra Pradesh
4	Sree Sakthi	9-10	45-50	2018	Non-branching, CMD resistant, high yielding, high starch content 27-32%, tolerant to post-harvest physiological deterioration Recommended for Kerala, Tamil Nadu and Andhra Pradesh
5	Sree Suvarna	7-8	45-50	2018	Non-branching, CMD resistant, medium starch content 25-27%, industrial use Recommended for Kerala, Tamil Nadu and Andhra Pradesh
6	Sree Reksha	8-9	40-50	2017	Non-branching, CMD resistant, starch content 27-31%, tolerant to post-harvest physiological deterioration Recommended for Kerala and Tamil Nadu
7	Sree Swarna	7-8	35-40	2015	Field tolerant to CMD, starch content 25.2%, suitable for both upland and lowland conditions Recommended for Kerala, Tamil Nadu and Andhra Pradesh
8	Sree Pavithra	9-10	35-40	2015	Medium starch content (24.4%), high K efficiency (243.65 kg tuber/kg K absorbed), suitable for soils which are inherently low to marginal in soil exchangeable K. Recommended for Kerala
9	Sree Padmanabha	9-10	29-30	2006	Resistant to CMD with normal yield, starch content 25-26% Recommended for Tamil Nadu and Andhra Pradesh

10	Sree Jaya	6-7	26-30	1998	Erect branching, excellent cooking quality, suitable for lowland as a rotation crop, susceptible to CMD, early maturing, starch content 24-27% Recommended for Andhra Pradesh, Kerala
11	Sree Vijaya	6-7	25-28	1998	Erect branching, excellent cooking quality, early maturing, suitable for lowland as a rotation crop, susceptible to spider mites and scale insects, starch content 27-30% Recommended for Bihar, Assam, Kerala
12	Sree Harsha	10	35-40	1996	Erect branching, good cooking quality, drought tolerant, starch content 38-41%, Recommended for Kerala
13	Sree Prakash	7	30-35	1987	Semi branching, suitable for lowland as a rotation crop, early maturing, starch content 29-31% Recommended for Kerala, Tamil Nadu, Andhra Pradesh, Assam

stages, can reduce root yield. Supplemental irrigation can be provided during extended dry periods where water is available. Drip or micro-irrigation, rainwater harvesting, farm ponds and efficient irrigation scheduling can improve water-use efficiency and enhance crop resilience during drought conditions.

Improved Drainage and Water logging Management: Cassava is sensitive to prolonged water logging, which can adversely affect root development and may increase disease problems. In areas receiving heavy or intense rainfall, farmers should adopt raised beds or ridges, field drainage channels and suitable land shaping to facilitate excess water removal. Maintaining good soil structure can also improve infiltration and reduce the duration of water stagnation in the field.

Intercropping and Crop Diversification: Intercropping cassava with suitable crops such as cowpea, groundnut, black gram, green gram and vegetables can improve the overall resilience of the farming system. Legume-based intercropping can contribute to soil fertility, while additional crops provide food and supplementary income. Diversification also reduces farmers' dependence on cassava alone and helps minimize the economic impact of crop failure caused by adverse climatic conditions.

Integrated Nutrient Management: Integrated nutrient management combines organic and inorganic nutrient sources to maintain soil fertility and improve crop productivity. Soil-test-based fertilizer application, farmyard manure, compost, green manure and crop-residue incorporation can improve soil health and nutrient availability. Balanced application of nutrients improves nutrient-use efficiency and helps cassava plants withstand environmental stresses more effectively.

Integrated Pest and Disease Management: Climate variability can influence the occurrence, distribution and severity of cassava pests and diseases. Integrated pest and disease management should therefore include the use of resistant or tolerant varieties, healthy planting material, regular field monitoring, field sanitation and conservation of natural enemies. Chemical pesticides should be used only when necessary and according to recommended practices. Early identification of pest and disease outbreaks can prevent serious crop losses.



Climate-Smart Weed Management: Effective weed management is particularly important during the early growth stages of cassava because weeds compete with the crop for water, nutrients, sunlight and space. Timely intercultural operations, mulching and suitable cover crops can suppress weeds while conserving soil moisture. Climate-smart weed management should minimize unnecessary soil disturbance and reduce erosion, particularly in areas vulnerable to heavy rainfall.

Agroforestry and Integrated Farming: Integrating cassava with trees, livestock and other crops can improve the resilience and sustainability of farming systems. Agroforestry can provide additional sources of food, fodder, fuel and income while improving soil protection and biodiversity.

Similarly, integration of cassava with livestock, poultry and other farm enterprises can provide diversified income sources and reduce farmers' dependence on a single agricultural activity.

Use of Weather and Climate Information: Access to timely weather and climate information can help farmers make better decisions regarding planting, irrigation, fertilizer application, pest management and harvesting. Rainfall forecasts, drought warnings, extreme-weather alerts and seasonal climate advisories can be incorporated into farm-level decision-making. Weather-based advisories can help farmers respond proactively to changing climatic conditions rather than reacting after crop damage has occurred.

Mechanization and Labour-Saving Technologies: Climate-smart cassava production can benefit from appropriate mechanization in land preparation, planting, weeding and harvesting. Labour-saving equipment can reduce dependence on manual labour and improve timeliness of farm operations. Mechanization is particularly useful when labour availability is limited or labour costs are increasing. Small-scale machinery can also support women and youth engaged in cassava production and value addition.

Climate-Smart Harvesting and Post-Harvest Management: Cassava roots are highly perishable after harvest, and delays in processing can result in deterioration and economic losses. Timely harvesting, careful handling, rapid transportation and prompt processing can reduce post-harvest losses. Processing cassava into chips, flour, starch and other value-added products can increase shelf life and provide additional income opportunities. Strengthening local processing and value-addition facilities can therefore contribute to climate-resilient livelihoods.

Value Addition and Market Diversification: Value addition is an important component of climate-smart cassava production because it can reduce farmers' dependence on fresh-root markets. Cassava can be processed into flour, starch, chips, bakery products, snacks and other value-added products. Developing local processing enterprises, particularly through women and youth groups, can create employment, improve income and reduce losses during periods of market or production uncertainty.

Farmer Capacity Building and Extension Support: Training and extension support are essential for promoting climate-smart cassava practices. Farmers need practical knowledge on climate-resilient varieties, soil and water management, pest and disease management, weather-based advisories and value addition. Demonstration plots, farmer field schools, participatory training and digital advisory services can help farmers understand and adopt these practices effectively.

Climate-smart cassava production should follow an integrated approach that combines improved varieties, sustainable soil and water management, diversified cropping, efficient pest and disease management, weather-based decision-making and value addition. The objective is not only to maintain cassava productivity under changing climatic conditions but also to reduce production risks, conserve natural resources, minimize losses and improve the income and resilience of farming households.

THE ROAD TO RESILIENCE

A climate-resilient cassava production system requires coordinated interventions at the farm, market, extension, and institutional levels. The major strategies include:

- **mproved agricultural practices:** Adoption of better farming techniques, climate-resilient varieties, appropriate planting times, and improved soil and water management can strengthen cassava production under changing climatic conditions.
- **Strengthened agricultural extension:** Extension services can help farmers understand changing weather patterns, select suitable varieties and planting dates, manage soil and water resources, and address emerging pests and diseases problems.
- **Climate information and technology:** Extension organisations can provide farmers with climate information, high-quality planting materials, demonstrations, and location-specific technologies to support informed decision-making.
- **Value addition and post-harvest diversification:** Processing cassava into chips, flour, starch, and other value-added products can reduce post-harvest losses, improve farmer returns, and reduce dependence on the sale of fresh cassava roots.
- **Policy and institutional support:** Better access to quality planting materials, credit, crop insurance, irrigation and water-conservation infrastructure, storage and processing facilities, markets, and reliable climate information can reduce farmers' vulnerability to climate risks.

CASSAVA HAS LONG BEEN AN IMPORTANT CROP FOR FOOD, NUTRITION AND LIVELIHOODS, PARTICULARLY IN TROPICAL AND SUBTROPICAL REGIONS, BUT CHANGING TEMPERATURES, IRREGULAR RAINFALL, DROUGHTS, FLOODS, AND EMERGING PEST AND DISEASE PRESSURES ARE CREATING NEW CHALLENGES FOR ITS PRODUCTION.

CONCLUSION

Cassava has long been an important crop for food, nutrition and livelihoods, particularly in tropical and subtropical regions, but changing temperatures, irregular rainfall, droughts, floods, and emerging pest and disease pressures are creating new challenges for its production. Building climate resilience at the farm level is therefore essential to protect productivity and the livelihoods of farming communities that depend on cassava for household income, food security and adequate nutrition. The way forward lies in integrating climate-resilient cassava varieties with climate-smart agronomic practices, improved soil and water management, and better post-harvest handling and value-addition opportunities. Strong agricultural extension, continuous research, farmer participation and supportive policies can help farmers identify and adopt suitable varieties and management practices according to local climate conditions. By bringing together farmers, researchers, extension agencies, policymakers and value-chain stakeholders, cassava can be better positioned to withstand climate uncertainties while continuing to provide food, nutrition and income, thereby ensuring that it remains a dependable crop for future generations.



SEAWEED FARMING

GREEN GOLD FROM THE BLUE SEA

Harshitha, S[1]., Dr. Atul Jayapal*[2]., Salma, M[3]., Aishwarya, V[3]., Surya Mithra J. Nair[4] and Revathy M. S[4].

1 – Agricultural Officer, Cherpu Krishi Bhavan, Thrissur, Kerala
2 – *Assistant Professor (Agronomy), College of Agriculture, Vellayani, Thiruvananthapuram
3 – M.Sc. student, Department of Agronomy, College of Agriculture, Vellayani, Thiruvananthapuram
4 – Ph.D. student, Department of Agronomy, College of Agriculture, Vellayani, Thiruvananthapuram

INTRODUCTION

India, one of the world's seventeen megadiverse countries, has a coastline of over 7,500 km that supports rich marine biodiversity and provides livelihoods to nearly 250 million people living in the coastal regions. However, climate change, ocean acidification, overfishing, and declining fish stocks are threatening the sustainability of traditional fisheries. In this context, seaweed farming has emerged as a promising alternative livelihood that can enhance the income of coastal communities, particularly women, while reducing pressure on marine fisheries. Seaweeds, or marine macroalgae, are valuable natural resources that provide habitat for marine organisms, improve coastal water quality by absorbing excess nutrients and carbon dioxide, and have wide-ranging applications in agriculture, food, pharmaceuticals, and various industries. Unlike conventional farming, seaweed cultivation does not require freshwater, fertile land, or chemical fertilizers, making it an environmentally sustainable enterprise. Although India has around 46 seaweed-based industries and immense scope for expansion, the sector remains largely untapped, offering significant opportunities for livelihood generation, sustainable agriculture, and the blue economy.

SEAWEED – STATUS/ DISTRIBUTION

More than 12,000 species of seaweeds are known worldwide, but only a small fraction is cultivated commercially. Asia is leading in production of seaweeds, accounting for more than 99 per cent of the global output, with China and Indonesia as the major producers. Today, seaweed farming is practised in more than 56 countries and is gaining importance as a sustainable source of food,

industrial raw materials and livelihood opportunities. In India, seaweed farming is still developing, but the country has great potential to expand this sector. Important commercial seaweeds such as Kappaphycus, Gracilaria, Sargassum and Ulva can be cultivated along suitable coastal areas. India's long coastline, including the Gulf of Mannar, Gujarat, Goa, Karnataka, Kerala, Lakshadweep and the Andaman and Nicobar Islands, is rich in seaweed diversity. Kerala is particularly promising for seaweed cultivation as the state is home to 147 seaweed species, accounting for about 17 per cent of the total species recorded in India. Among these, 42 species have economic importance. This rich diversity, together with Kerala's coastal resources, provides a strong foundation for promoting seaweed farming, creating livelihood opportunities and developing value-added seaweed-based products.

CLASSIFICATION OF SEAWEEDS

Seaweeds are broadly classified into three groups based on their pigments - brown algae, green algae and red algae. Brown algae, such as Sargassum, Turbinaria and Laminaria, are rich in alginates and are widely used as thickening and gelling agents in the food, pharmaceutical and cosmetic industries. Green algae, including Ulva, Enteromorpha and Caulerpa, are used as food, animal feed and as biofertilizers. Red algae, such as Gracilaria, Kappaphycus, Hypnea and Gelidiella, are among the most commercially important seaweeds. They are the major sources of agar and carrageenan, valuable substances widely used in food processing, pharmaceuticals, cosmetics and biotechnology. Together, these three groups make seaweeds an important natural resource with great potential for food, industry, agriculture and livelihood generation.

SEAWEED FARMING

Seaweed farming is emerging as a promising and sustainable livelihood option for coastal communities. It provides an additional source of income and can help reduce dependence on capture fisheries. In several Asian countries, seaweed farming has already contributed to improving the socio-economic status of small-scale fishers. India also has considerable potential to expand seaweed cultivation, with nearly 24,000 hectares of shallow coastal waters identified as suitable for farming. Pilot projects have been undertaken in Tamil Nadu, Kerala, Karnataka, Maharashtra, Gujarat and Andhra Pradesh. Among these states, Tamil Nadu has emerged as the leading producer due to its favourable coastal conditions. However, the success of seaweed farming depends on several factors, including the selection of suitable sites and species, adoption of appropriate cultivation methods and proper maintenance of the farms. Easy availability of inputs, transportation facilities and access to markets are also important for making seaweed farming profitable and sustainable.

SEAWEED FARMING IS EMERGING AS A PROMISING AND SUSTAINABLE LIVELIHOOD OPTION FOR COASTAL COMMUNITIES. IT PROVIDES AN ADDITIONAL SOURCE OF INCOME AND CAN HELP REDUCE DEPENDENCE ON CAPTURE FISHERIES.

SELECTION OF SITE

Choosing a suitable site is the first step towards successful seaweed cultivation. Good sites should have clean coastal waters, a temperature of around 27 - 30°C, salinity of 28 - 38 ppt and moderate water currents of 0.2 - 0.4 m s-1. The area should also be free from heavy fishing activity, ornamental fish collection and other disturbances that may affect seaweed growth. Easy access to farming inputs, transportation and markets is equally important for making cultivation of sea weeds profitable. In Kerala, about 80 hectares of coastal waters have been identified as suitable for seaweed cultivation. Promising locations include Vizhinjam (Thiruvananthapuram), Thirumullavaram (Kollam), Elathur, Puthiyappa and Thikkodi (Kozhikode), and Padanna and Bekal (Kasaragod). These areas offer good opportunities for expanding seaweed farming and developing it as a sustainable livelihood for coastal communities.

SELECTION OF SEEDLINGS

Seaweed is commercially propagated mainly through vegetative propagation using healthy and disease-free branches. The planting material should be fresh, healthy, smooth and free from any signs of damage or

infection. Selected branches are cut using a sharp stainless-steel knife and carefully tied at their strongest portions. Proper handling and tying help prevent breakage during cultivation, promote better establishment and ultimately support higher yields.

SEAWEED FARMING METHODS

Depending on the type of seaweed and the local conditions, there are several methods used for farming seaweed.

i. Floating bamboo raft method (Kappaphycus farming)

The floating bamboo raft method is one of the most widely used techniques for growing seaweeds in calm and shallow coastal waters. A bamboo raft, measuring about 3.6 m x 3.6 m, is fitted with polypropylene ropes, on which small seaweed fragments weighing about 150 - 200 g are tied at 15 cm intervals. Each raft can hold around 60 - 80 kg of planting material. A protective fish net is fixed below the raft to reduce grazing by herbivorous fish, while anchors keep the raft stable in the water. The rafts are generally placed in near-shore waters at a depth of 1 - 1.5 m. Under suitable conditions, the crop can be harvested within 45 - 60 days, making this method simple, practical and suitable for coastal farmers.

ii. Longline or monoline method

The longline or monoline method is suitable for coastal areas with moderate wave action and shallow waters. In this method, ropes carrying seaweed fragments are stretched between rows of firmly fixed poles. Small seaweed cuttings weighing about 150 g are tied to the ropes at 15 cm intervals.



Imta Method

Floats, such as used PET bottles, are attached to the ropes to keep them above the water. Protective HDPE nets can be used to reduce damage caused by waves and grazing by fish. This method is simple, requires relatively low investment and can provide yields comparable to the bamboo raft method. Depending on the seaweed species and growing conditions, the crop can generally be harvested within 45 - 60 days, making it a practical option for coastal farmers.

iii. Tube net method

The tube net method is particularly suitable for coastal areas with strong wave action, where conventional raft systems may be difficult to maintain. In this method, seaweed fragments are placed inside long HDPE tube nets, which are kept afloat using floats and securely anchored to the sea floor. The enclosed structure protects the seaweed from strong waves and grazing by herbivorous fish, helping to improve survival and growth. The crop is generally ready for harvest within 45 - 60 days. About four tube-net units can produce yields comparable to one bamboo raft, making the method suitable for areas exposed to stronger wave action. The commercial potential of this method has been demonstrated by ICAR-CMFRI at Chetlat Island, Lakshadweep, where large-scale tube-net cultivation produced substantial quantities of seaweed while also creating employment opportunities, particularly for women associated with self-help groups. The project generated thousands of man - days of employment, highlighting the potential of seaweed farming as a sustainable livelihood option for coastal communities.

iv. Integrated Multi-Trophic Aquaculture (IMTA)

Integrated Multi-Trophic Aquaculture (IMTA) is an eco-friendly farming system in which seaweeds are cultivated along with fish, shrimp, shellfish and other aquaculture species. In this system, seaweeds absorb dissolved nutrients released from fish and

shrimp farming, helping to improve water quality while providing an additional crop for farmers. IMTA offers several benefits to coastal farmers. It helps reduce environmental pollution, recycles nutrients and provides an additional source of income, thereby reducing production risks. Compared with conventional aquaculture, IMTA can improve water quality, increase overall farm productivity and generate higher returns by making better use of available resources. Thus, IMTA provides a sustainable and economically viable approach for the future development of coastal aquaculture.

MAINTENANCE

Proper maintenance is essential for healthy seaweed growth and higher yields. Farmers should inspect the farm regularly to monitor plant health and the condition of rafts, ropes, and anchors. Damaged or missing seedlings should be replaced promptly, while unwanted seaweeds, sediments, and other fouling materials attached to the ropes should be removed periodically. Worn-out bamboo poles, ropes, and nets should also be repaired or replaced to ensure the long-term sustainability and efficiency of the seaweed farm.

HARVEST

Seaweeds attain harvest maturity within 45 - 60 days after planting. During harvesting, the crop should be handled carefully and placed on clean tarpaulin sheets to avoid contamination with sand or silt. Healthy, vigorous plants from the harvest should be selected and reserved as planting material for the next cultivation cycle, ensuring good-quality seedlings and sustained productivity.

POST-HARVEST HANDLING

Proper post-harvest handling is essential to maintain the quality of seaweed. After harvesting, the seaweed should be cleaned thoroughly by removing fouling organisms, debris, and tying materials, followed by washing with clean seawater. The harvested crop should be dried on raised platforms or clean surfaces rather than directly on sand to avoid contamination. During drying, the seaweed should be turned regularly to ensure uniform moisture removal and protected from rain using tarpaulin sheets. Once sufficiently dried, the seaweed is packed in plastic sacks, stored in a dry place, and transported to processing industries for value addition.



Longline Method

USES OF SEAWEED FARMING

AGRICULTURE

Seaweeds have emerged as valuable natural resources in agriculture because of their multiple roles as plant bio-stimulant, biofertilizers, soil conditioners and biosorbents. Application of seaweed extracts has been shown to improve crop growth, yield and quality by enhancing nutrient uptake, photosynthesis and overall plant vigour. In crops such as rice, banana and sesame, seaweed-based products is found to increase yield, improve product quality and enhance farmers' economic returns while reducing dependence on chemical fertilizers. Seaweed extracts also help crops tolerate environmental stresses such as drought and salinity. They improve water retention, maintain photosynthetic pigments, enhance the accumulation of protective compounds such as proline, and stimulate antioxidant activity, enabling plants to withstand adverse conditions and sustain growth.

Apart from promoting plant growth, seaweed extracts can strengthen the natural defense mechanisms of plants against diseases and pests. The bioactive compounds present in seaweeds can suppress several plant pathogens and reduce disease severity. Some seaweed species also

possess natural insecticidal properties that can help manage crop pests. Seaweed-based coatings can also help extend the shelf life of fruits and vegetables by reducing moisture loss, maintaining firmness and preserving freshness during storage. When applied to soil, seaweed products can improve soil health by adding organic matter and enhancing the availability of essential nutrients. They can also stimulate beneficial soil microorganisms, improving soil biological activity and fertility. Another important benefit of seaweeds is their ability to bind heavy metals. This property can help reduce the uptake of toxic metals by plants and support the restoration of contaminated soils. With these multiple benefits, seaweed-based products offer an environmentally friendly and sustainable option for promoting climate-resilient agriculture.

ENVIRONMENTAL APPLICATIONS

Seaweed farming offers several environmental benefits, making it a promising nature-based solution for climate change mitigation and coastal ecosystem restoration. Seaweeds act as natural carbon sinks by absorbing carbon dioxide from the atmosphere. They also help improve coastal water quality by taking up excess nutrients from seawater. Their growth can contribute to reducing ocean acidification by increasing dissolved oxygen levels and seawater pH. Seaweeds may also help control harmful algal blooms by absorbing excess nutrients and through natural allelopathic effects. Seaweed beds provide additional protection to coastal areas by reducing wave energy and soil erosion. They also serve as important breeding, feeding and nursery grounds for fish, shrimp, crabs and other marine organisms. These multiple ecosystem services make seaweed cultivation an important tool for strengthening climate resilience, maintaining healthy coastal ecosystems and supporting sustainable fisheries.

FOOD INDUSTRY

Seaweeds have long been consumed as nutritious sea vegetables in countries such as China, Japan and South Korea. They are rich in carbohydrates, proteins, essential amino acids, vitamins, minerals and health-promoting polyunsaturated fatty acids, making them comparable to conventional vegetables in nutritional value. A wide range of edible seaweeds is consumed in the form of soups, salads, snacks, sushi wraps and pickles, highlighting their importance as a healthy and sustainable food source.

SEAWEED BIOMASS IS A PROMISING RENEWABLE FEEDSTOCK FOR BIOENERGY PRODUCTION. AS A THIRD-GENERATION BIOFUEL RESOURCE, IT CAN BE CONVERTED INTO GASEOUS FUELS SUCH AS BIOGAS AND BIOMETHANE WITH HIGH ENERGY POTENTIAL.

OTHER INDUSTRIAL APPLICATIONS

Seaweeds have diverse industrial applications owing to their abundance of bioactive compounds and polysaccharides. They are the primary source of commercially important hydrocolloids such as alginate, agar and carrageenan, which are widely used as gelling, thickening and stabilizing agents in the food, pharmaceutical, cosmetic, textile, paper and printing industries. Seaweeds also contain valuable bioactive compounds with antioxidant, antimicrobial, antiviral, anti-inflammatory and other health-promoting properties, making them important ingredients in pharmaceuticals and nutraceuticals. In addition, several seaweed species are used as livestock and poultry feed, where they improve nutrition, animal health and productivity.

BIOFUEL PRODUCTION

Seaweed biomass is a promising renewable feedstock for bioenergy production. As a third-generation biofuel resource, it can be converted into gaseous fuels such as biogas and biomethane with high energy potential. Unlike land-based biofuel crops, seaweeds do not compete for arable land or freshwater, making them an environmentally sustainable alternative for renewable energy generation.

BIOPLASTICS

Seaweeds are emerging as a sustainable raw material for the production of biodegradable bioplastics. Their abundant biomass and naturally occurring compounds such as alginates



Tubenet Method

and carrageenan make them suitable for developing eco-friendly packaging materials. Seaweed-based bioplastics offer a renewable alternative to conventional plastics and can help reduce plastic pollution and promote environmental sustainability.

CHALLENGES AND WAYS TO OVERCOME

Seaweed aquaculture, despite its significant economic, environmental, and health benefits, encounters several challenges that hinder its successful development.

i. Lack of infrastructure, marketing facilities and awareness

Despite its immense potential, seaweed farming faces several challenges, including inadequate storage, transportation and processing facilities, weak market linkages, price fluctuations, and limited awareness about suitable farming sites, value-added products and market opportunities. Strengthening infrastructure, providing financial support and insurance, ensuring fair pricing and efficient marketing systems, establishing processing units near cultivation areas, and creating awareness through training and extension programmes will be essential for promoting profitable and sustainable seaweed farming.

ii. Ice-ice disease and epiphyte infestation

The major biological constraints in seaweed cultivation are ice-ice disease and epiphyte infestation, both of which reduce yield and quality. Ice-ice disease causes whitening and breakage of seaweed branches under unfavourable environmental conditions such as extreme temperatures, salinity fluctuations and intense sunlight. Epiphytes, including algae, fungi and bacteria, grow on cultivated seaweeds, suppressing growth and reducing biomass. These problems can be minimized through regular crop monitoring, removal of epiphytes, proper farm maintenance and timely harvesting. When ice-ice disease occurs, the affected crop should be harvested and cultivation restarted using healthy planting material.

iii. Natural calamities

Seaweed farming is highly vulnerable to adverse weather events such as storms and cyclones, as cultivation is generally carried out in shallow coastal waters. These events can cause severe damage to farms and substantial biomass loss. Timely weather forecasting, premature harvesting before extreme weather, and preserving healthy seedlings in deeper waters for replanting can help minimize losses and improve the resilience of seaweed farming.

iv. Threat to coral reefs

The cultivation of certain seaweed species, particularly

Kappaphycus alvarezii, requires careful management because of their invasive nature. Uncontrolled spread can smother coral reefs and threaten marine biodiversity. Regular monitoring of reef ecosystems, avoiding seaweed farming near coral reefs, and promoting the cultivation of native seaweed species are essential to minimize ecological risks while ensuring sustainable seaweed production.

v. Conflict with other local users

Expansion of seaweed farming can lead to conflicts with fisheries and tourism due to competition for coastal space and interference with fishing and recreational activities. Proper coastal zone planning, stakeholder participation and integrated management are essential to balance the interests of seaweed farmers, fishers and the tourism sector, ensuring sustainable and conflict-free development.

FUTURE PROSPECTS

Seaweed farming has immense potential to support India's blue economy through increased production, value addition and exports. It can generate employment and livelihood opportunities for coastal communities, particularly women and small-scale fishers. The growing use of seaweeds in food, agriculture, pharmaceuticals, biofertilizers, bio-stimulants, bioplastics and biofuels further strengthens their economic importance. With continued research, policy support and infrastructure development, seaweed cultivation can contribute significantly to sustainable agriculture, renewable energy, nutritional security and environmental conservation.

CONCLUSION

Seaweed farming offers immense potential for sustainable economic development, environmental conservation, and livelihood enhancement in India. It supports the Blue Economy by generating income for coastal communities while providing eco-friendly products for agriculture, food, health, industry, and renewable energy. Addressing challenges related to infrastructure development, market access, and sustainable management through focused research, policy support, and community participation will be essential for unlocking the full potential of seaweed farming as a resilient coastal enterprise. With its ability to nurture coastal livelihoods, restore marine ecosystems, and provide sustainable solutions for a changing world, seaweed truly stands as the 'Green Gold from the Blue Sea.'



EMERGING TECHNOLOGIES

Transforming Market Intelligence for Farmers From Data to Better Farm and Market Decisions



Ardra S Krishnan,
P. Prakash* and
V.S. Santhosh Mithra

ICAR-Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram 695017, Kerala

*Corresponding author:
prakashctcri@gmail.com

INTRODUCTION

Until recently, market intelligence relied largely on quarterly reports, costly analyst subscriptions and teams that manually screened news and market information. Emerging technologies are changing this model by reducing the time required to collect, process and interpret information. AI driven systems can now analyse large volumes of data within minutes and deliver insights in near real time. The focus is therefore shifting from simply accumulating data to converting relevant information into timely decisions.

Businesses increasingly combine data from multiple sources and use advanced analytical technologies to identify patterns, trends and emerging opportunities. Market intelligence platforms are evolving from systems that merely collect and store information into decision support tools that analyse, interpret and present results when they are needed. These developments are particularly relevant to agriculture, where production and marketing decisions are influenced by prices, demand, weather, supply conditions and consumer preferences.

WHY MARKET INTELLIGENCE IS CHANGING

Artificial intelligence (AI) has significantly changed the way market information

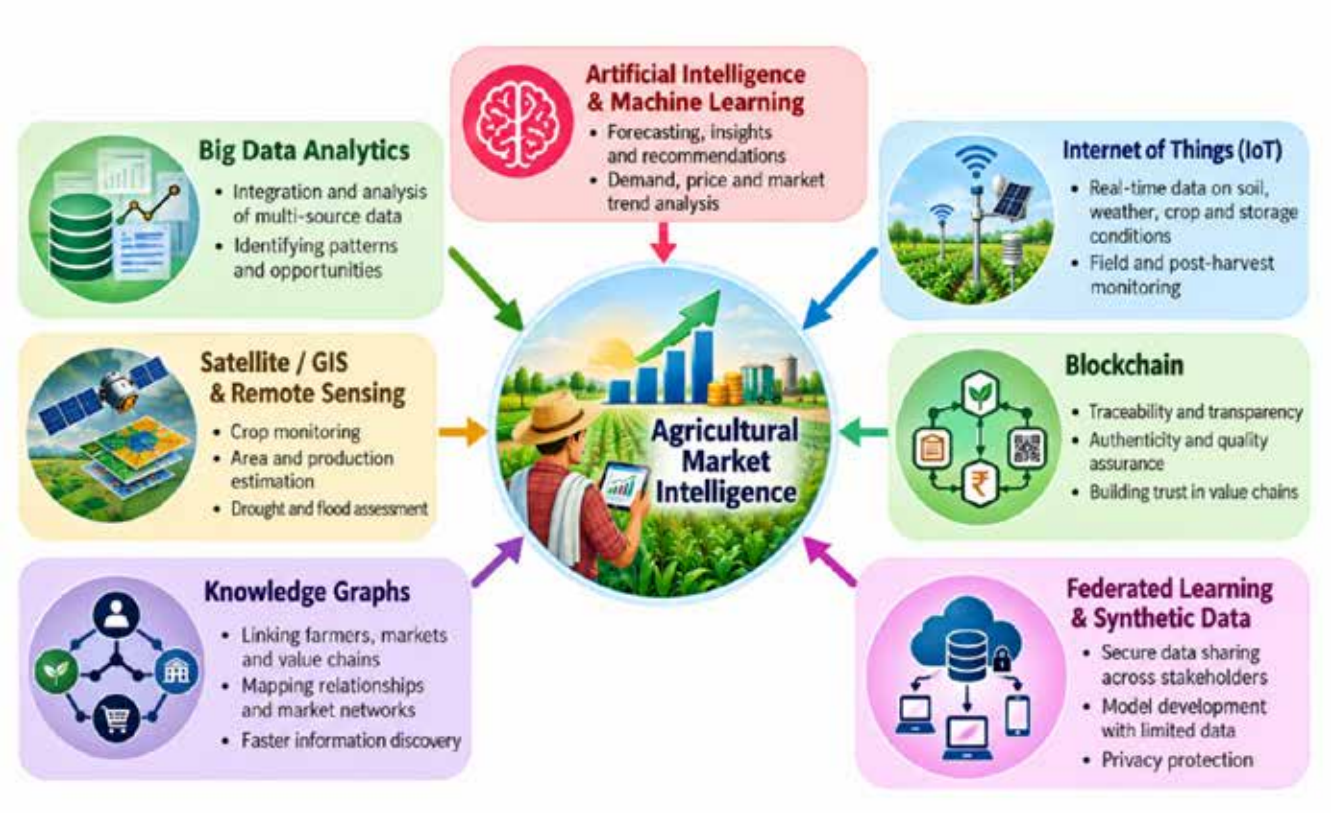


Fig 1. Emerging technologies for agricultural market intelligence

is collected and analysed. Large language models (LLMs) can summarise documents, identify relevant information and support responses to market related questions. They can also assist with demand analysis and the assessment of consumer preferences. The greatest potential arises when AI complements human expertise rather than attempting to replace it.

Natural language processing (NLP) can examine large volumes of text from news reports, market updates, company documents and other sources, reducing the time required for manual screening and coding. At the same time, the Internet of Things (IoT) and connected devices generate continuous behavioural and operational data. When combined with analytical tools, these data provide insights into what is actually happening rather than relying entirely on reported intentions.

Together, these developments are moving market intelligence towards a more continuous and data driven system. However, human verification remains essential because AI-generated outputs may contain errors, while predictive models depend on the quality and relevance of the data used to train them.
Fig 1.

1. Artificial Intelligence (AI)

Artificial intelligence is one of the most influential technologies in modern market intelligence. Generative AI and large language models such as Claude, ChatGPT and Gemini can process and summarise large volumes of unstructured information, including news reports, company announcements and market documents. They can help analysts identify important developments and obtain concise answers to specific questions.

Agentic AI extends these capabilities by carrying out sequences of tasks such as searching, cross checking information and compiling reports. For example, AI agents can support continuous monitoring of market developments and alert users when relevant changes occur. Natural language processing helps extract entities, relationships and sentiment from text, while predictive analytics and machine learning use historical information to forecast demand, prices and other market variables.

Despite these capabilities, AI outputs require verification. Generative and agentic

systems may produce plausible but incorrect information, while predictive models can perform poorly when market conditions change substantially. Human review is therefore particularly important for numerical information, quotations, forecasts and consequential decisions.

2. Federated Learning

Federated learning enables machine learning models to be trained across multiple decentralised data sources without transferring the underlying raw data to a central location. Instead, participating systems share model updates. This approach can support collaboration where organisations need the benefits of shared analysis but cannot freely exchange proprietary or sensitive information.

Potential applications include supply chain forecasting, benchmarking and risk analysis across companies or regions. However, implementation can be technically complex and adoption remains more limited than that of conventional machine learning systems. Its value is particularly relevant where data confidentiality, governance and data residency requirements restrict conventional data sharing.

FEDERATED LEARNING ENABLES MACHINE LEARNING MODELS TO BE TRAINED ACROSS MULTIPLE DECENTRALISED DATA SOURCES WITHOUT TRANSFERRING THE UNDERLYING RAW DATA TO A CENTRAL LOCATION.

3. Big Data Analytics and Data Integration Platforms

Big data analytics combines and analyses large volumes of structured and unstructured information from multiple sources. It provides the infrastructure required to integrate web traffic, social media signals, financial information, patent records, employment trends and other indicators into a consolidated view of markets and competitors.

These platforms can support continuously updated dashboards and help identify relationships that may not be visible in individual datasets. However, data integration is often the most challenging part of implementation because information differs in format, quality and frequency of updating. More data alone does not guarantee better decisions; effective analytical processes are necessary to convert large datasets into actionable intelligence.

4. Internet of Things (IoT) Data Streams

The Internet of Things connects sensors and devices that generate continuous, real time information. In agriculture and supply chains, IoT devices can monitor soil moisture, temperature, irrigation, storage conditions, transport, inventory and equipment performance.

For market intelligence, these data can provide timely information about production conditions, inventory and supply disruptions. Linking field and supply chain information with market demand can improve planning for harvesting, storage, transport and sale. However, IoT systems require suitable infrastructure, data management capacity and clear approaches to privacy, consent and data ownership.

5. Satellite Imagery, GIS and

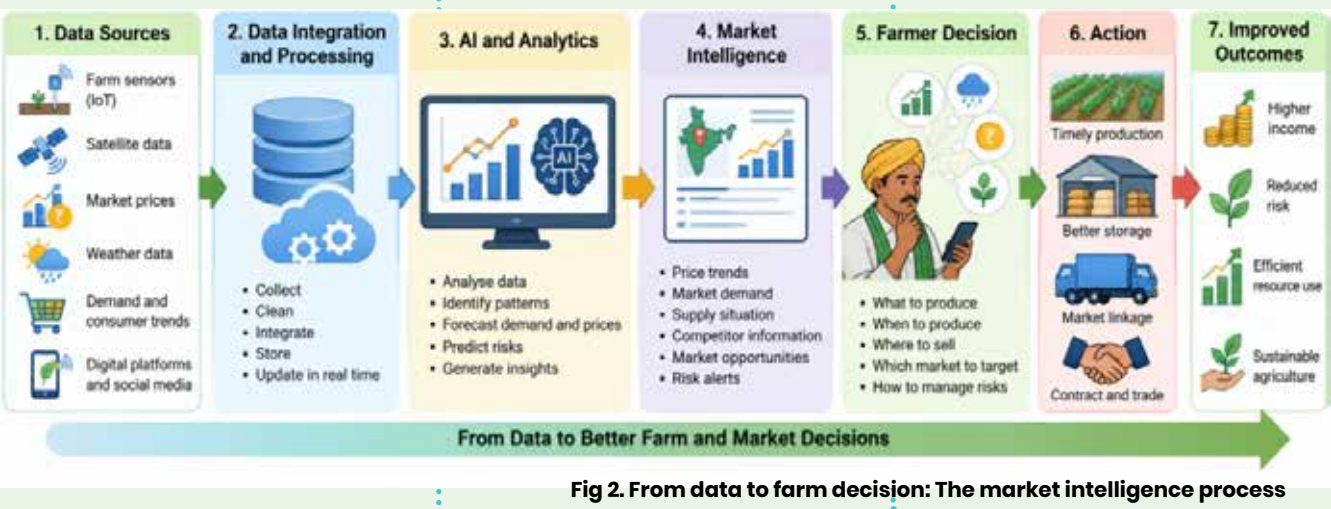


Fig 2. From data to farm decision: The market intelligence process



Fig 3. Key technologies, agricultural applications and benefits for farmers

Remote Sensing

Satellite imagery, geographic information systems (GIS) and remote sensing provide information on physical activity over large areas. Optical, radar and thermal observations can be combined with geographic data to monitor crop areas, crop condition, infrastructure and other changes on the ground.

For market intelligence, these technologies can support assessment of agricultural production, monitoring of supply conditions and early identification of changes that may influence commodity markets. They can also support procurement, storage, transport and marketing decisions. Their limitations include the cost of high resolution imagery and the need for specialised analytical methods to convert images into reliable market signals.

6. Block chain and On Chain Analytics

Blockchain is a distributed ledger technology that records transactions in a transparent and tamper resistant manner. On chain analytics refers to tools that analyse transaction information recorded on public block chains. In agriculture, block chain can support traceability by recording the movement of products through different stages of a value chain.

Traceability can be useful where product origin, quality and authenticity are important. It can strengthen the documentation of transactions and improve information flow between producers, intermediaries and buyers. However, block chain remains more specialised than AI and big-data analytics, and its usefulness depends on the quality of the information entered into the system.

7. Synthetic Data and Synthetic Consumers

Synthetic data are artificially generated datasets designed to reproduce selected characteristics of real world data. In market research, synthetic consumer profiles can be used to conduct preliminary assessments of products, prices or communication strategies before investing in extensive field research.

Synthetic data can also help train analytical models when real datasets are limited, sensitive or expensive to collect. However, synthetic observations are derived from existing patterns and may not adequately represent unexpected changes or the full complexity of human preferences. They are therefore better viewed as a complement to, rather than a replacement for, real consumer research.

8. Knowledge Graphs

Knowledge graphs organise information as interconnected entities and relationships rather than as isolated records. In market intelligence, they can connect companies, products, suppliers, buyers, investors,

technologies and events to reveal relationships that may be difficult to identify from individual datasets.

This approach can help users trace indirect signals, such as relationships between suppliers, patents, investors and competitors. Knowledge graphs can become more valuable as additional reliable information is incorporated. Their effectiveness, however, depends on the quality, completeness and consistency of the underlying data. Fig 2.

APPLICATIONS FOR FARMERS AND AGRICULTURAL VALUE CHAINS

For farmers, market intelligence is useful only when information supports a practical decision. Decisions about what to produce, when to harvest, where to sell, how much to store and which market to target depend on timely information about prices, demand, supply, weather and crop conditions. (Fig 3)

Emerging technologies can strengthen this process without replacing farmers' experience and local knowledge. AI and machine learning can support price and demand analysis; IoT sensors can provide real time information on soil, crops and storage; satellite imagery and GIS can help assess crop area and production conditions; and digital platforms can connect market information with farmers, Farmer Producer Organisations (FPOs), traders and processors.

The value of these technologies increases when information from different sources is integrated. For example, crop condition data from sensors or satellites can be combined with weather forecasts, market arrivals and price information to support harvesting and marketing decisions. Similarly, traceability systems can help document product origin and movement through the value chain, particularly for quality sensitive and differentiated products.

Extension agencies and agricultural institutions can use these technologies to provide more timely and location specific advisories. However, effective use requires attention to digital literacy, affordability, data privacy, connectivity, data quality and the reliability of AI generated information. Technology should therefore be treated as a decision support mechanism rather than a substitute for farmer knowledge or professional judgement. Fig 4.



Fig 4. Digital market intelligen ceecosystem for farmers and FPOs

CONCLUSION

Market intelligence is evolving from periodic information collection into a more continuous decision support system. AI, big data analytics, IoT, satellite imagery, GIS, block chain, synthetic data and knowledge graphs each contribute different capabilities to this transformation.

The central lesson is that access to more data does not automatically lead to better decisions. Reliable data, appropriate analytical methods and human verification are essential for converting information into useful intelligence. Technologies such as AI and big data analytics are becoming increasingly mainstream, while federated learning, block chain analytics, synthetic data and knowledge graphs remain more specialised and application specific.

For agriculture, the greatest potential lies in combining emerging technologies with farmers' experience, local knowledge and effective extension support. The objective should be straightforward: provide the right information at the right time so that farmers and agricultural value chain actors can produce efficiently, market strategically and improve the sustainability of farm based livelihoods.



POINTED GOURD

AN UNDERUTILIZED VEGETABLE WITH HIGH NUTRITIONAL SIGNIFICANCE

Dr. Nisha S K.,

Assistant Professor, Dept. of Vegetable Science, College of Agriculture, Vellayani (Mobile No. 9447890944)

Sanjay R.,

Ph.D Scholar, Dept. of Vegetable Science, College of Agriculture, Vellayani (Mobile No. 6383689871)

Nallabothula Harika

(Ph.D Scholar), Dept. of Vegetable Science, College of Agriculture, Vellayani (Mobile No. 9704813290)

INTRODUCTION

Pointed gourd (Trichosanthes dioica Roxb.), commonly known as parwal or potol, is an important perennial cucurbitaceous vegetable cultivated extensively in India, Bangladesh and Nepal. It occupies a prominent place in the diet of eastern and northern India owing to its pleasant taste, digestibility and nutritional richness. Among cucurbitaceous vegetables, pointed gourd is often referred to as the "King of Gourds" because of its superior nutritional value and health promoting properties. Recent studies have highlighted its potential role in addressing micronutrient deficiencies, improving dietary quality and contributing to nutritional security.

Unlike most annual cucurbits, pointed gourd is a perennial, dioecious and vegetatively propagated crop. Male and female flowers are borne on separate plants, making the maintenance of an appropriate proportion of male and female plants important for effective pollination and fruit production. The crop possesses tuberous roots that enable it to survive adverse seasons and produce new shoots when favourable conditions return.

The immature fruits are generally green, cylindrical to oblong, and may possess characteristic white or pale green stripes. The fruits are valued for their nutritional quality and are used in curries, fried preparations, stuffed dishes and other culinary products.

NUTRITIONAL COMPOSITION

Pointed gourd is a low calorie vegetable rich in essential nutrients. The edible fruit contains 2.2 g carbohydrates, 2.0 g protein,

0.3 g fat and 3.0 g dietary fibre per 100 g fresh weight. It is also a valuable source of vitamins and minerals, containing 30 mg calcium, 40 mg phosphorus, 1.7 mg iron, 1.53 mg carotene, 0.05 mg thiamine, 0.5 mg niacin and 29 mg vitamin C per 100 g of edible portion. The low fat content coupled with appreciable fibre makes it a desirable component of a healthy diet.

Compared with several other cucurbits, pointed gourd possesses higher nutritional density. It contains substantially more protein than bottle gourd and higher vitamin A content than ridge gourd, snake gourd and ash gourd. Such nutritional superiority makes pointed gourd an important vegetable for improving the quality of diets in both rural and urban population.

ETHNOPHARMACOLOGICAL USES

Fruits are used in tribal areas of West Bengal as a remedy for reducing chicken pox scars. Juice of leaves of pointed gourd is used as tonic, febrifuge and in subacute cases of enlargement of liver and spleen. In Charaka Samhita, leaves and fruits are used for treating alcoholism and jaundice. Leaves are used in edema and alopecia. It is also used as antipyretic, diuretic, cardiotonic and laxative. Leaves, fruits and seeds possess anti-hyperglycaemic properties.

BIOACTIVE COMPOUNDS

Apart from conventional nutrients, T. dioica contains diverse phytochemicals, including triterpenes, sterols, flavonoids, phenolics, tannins and cucurbitacins. Compounds such as cucurbitacin B, lupeol, ⍺-amyrin, ⍺-amyrin and other triterpenoids have been reported in different plant parts. Roots contain colocynthin, hentriacontane, cucurbita-5,24-dienol and other non-bitter glycosides, essential oil, fixed oil and tannin. Seeds contain elaeosteric, linoleic, oleic and other saturated fatty acids.

ORIGIN AND DISTRIBUTION

Pointed gourd is a native of India. The crop is widely cultivated in eastern and northern India mainly Bihar, West Bengal, Uttar Pradesh and Assam, with cultivation also extending to Odisha, Madhya Pradesh, Maharashtra and some parts of Andhra Pradesh and Tamil Nadu.

Varieties: Kashi Purwal-141, Kashi Suphal, Kashi Amulya, Kashi Alankar, Rajendra Parwal-1, Rajendra Parwal-2, Swarna Rekha, Swarna Alaukik, Narendra Parwal-260, Narendra Parwal-307, Narendra Parwal-604

CLIMATE AND SOIL

Pointed gourd is adapted to warm and humid tropical and subtropical conditions. The optimum temperature for proper growth ranges from 25 to 35°C. It grows actively during warm periods and generally enters a period of dormancy under cool winter conditions. The crop grows well in fertile, well drained sandy loam to loamy soils rich in organic matter. Good drainage is particularly important because pointed gourd is sensitive to prolonged waterlogging. A soil pH of 6.0–7.0 is generally suitable.

PROPAGATION

Commercial cultivation of pointed gourd is predominantly based on vegetative propagation through vine or root suckers. Seed is not recommended as a commercial propagating material because of poor seed germinability and viability, production of 50% male plants from seeds and long time for flowering.

Cuttings are taken from one year old vines during October, when fruiting is over. The ratio of pistillate and staminate cuttings is 9:1. Different methods of planting can be adopted.

Straight method: Cuttings of 60-70 cm length is buried horizontally in soil with one or both the ends exposed and covered with soil and well decomposed farm yard manure.

Ring method: Long vines of 60-75 cm are coiled in the shape of ring and planted in field keeping both ends exposed.



Lunda or Lachhi method: Here, 1.0-1.5 m long vines with 6-8 nodes are folded in a figure '8' and planted 3-5 cm deep in prepared field with the knot in the centre.

Moist lump method: About 60-90 cm long vine is encircled over a lump of moist soil leaving about 15 cm free at both ends. The soil lump is then buried 10 cm deep in a well prepared pit keeping both the ends of cutting exposed. The buried cutting will root and buds will sprout on the exposed part.

LAND PREPARATION AND PLANTING

The land should be thoroughly ploughed to obtain a fine tilth and good drainage. Pits or planting basins may be prepared according to the selected planting system and spacing. A spacing of 1.5 m x 1.5 m if trained; otherwise, 2.0 m × 2.0 m can be adopted. Female and male plants ratio should be kept at 10: 1.

MANURES AND FERTILIZER MANAGEMENT

Pointed gourd is a long duration perennial crop and therefore requires adequate nutrient availability for sustained vegetative growth and repeated fruit production. Application of well decomposed farmyard manure or compost before planting improves soil structure, water holding capacity and nutrient availability. Soil test based fertilizer application can be resorted to, which depends on cultivar, soil type and cropping system.

TRAINING AND PRUNING

Training is an important component of pointed gourd cultivation because the crop produces vigorous climbing vines. The vines may be trailed on the ground, particularly in lighter soils and areas where this practice is suitable; or trained on a bower/trellis, which provides better exposure of foliage and improves aeration. Bower or trellis training is particularly useful in intensive cultivation systems because it facilitates better canopy management and harvesting. Excessively crowded and weak shoots should be removed periodically to maintain an open canopy. Proper training also helps to reduce fruit contact with moist soil, thereby helping to minimize fruit decay.

HARVESTING

Pointed gourd is harvested primarily for its immature tender fruits. Fruits should be harvested while they are green, tender and marketable, before excessive seed development and hardening occur. Harvesting should preferably be carried out at regular intervals because fruits develop rapidly under warm conditions. Delayed harvesting results in over aged fruits with reduced tenderness and lower market quality. Regular harvesting encourages continued flowering and fruit production and is therefore important for maximizing marketable yield.

CONCLUSION

The perennial nature of the crop, together with considerable variability for yield, fruit characteristics and nutritional quality, makes pointed gourd an important crop for genetic improvement, nutritional breeding and sustainable vegetable production. Recent studies highlighting nutritional diversity among genotypes further strengthen the potential for developing superior cultivars with enhanced yield, quality and nutritional value.

References

Datta, K. and Sarkar, D. (2025). Exploring Trichosanthes dioica: A comprehensive study of its ethnomedical uses, phytochemistry, pharmacology and toxicity. Chemistry and Biodiversity, 22(12): e01188.

Khandaker, M., Boyce, A.N. and Imam, M.Z. (2018). Trichosanthes dioica Roxb.: A vegetable with diverse pharmacological properties. Food Science and Human Wellness, 7(1): 34–48.

Kumar, N., Singh, S., Manvi, M. and Gupta, R. (2012). Trichosanthes dioica Roxb.: An overview. Pharmacognosy Reviews, 6(11): 61–67.

Sharma, S., Sinha, R., Singh, A.K., Meena, Y., Behera, T.K. and Barman, K. (2023). An umbrella review on ethnomedicinal, pharmacological and phytochemical profile of pointed gourd (Trichosanthes dioica Roxb.): A bioactive healthy vegetable of Indian subcontinent. Food Chemistry Advances, 3:100433.

Singh, K. P. and Bahadur, A. (2015). Olericulture II Vegetable Production and Improvement. Kalyani Publishers.

Sinha, A.K., Bhavana, P., Singh, A.K., Ranjan, J.K., Choudhary, H., Mishra, G.P., et al. (2026). Exploring the nutritional riches of pointed gourd (Trichosanthes dioica Roxb.): A multivariate approach for selection of nutritionally superior genotypes for breeding programmes. Frontiers in Plant Science, 17:1865400.

FROM RED TO BLUE



HOW BREEDING IS CHANGING TOMATO COLOURS

Raman Selvakumar and Paresh Chaukhande

ICAR–Indian Agricultural Research Institute, New Delhi – 110 012

On a February morning in 2024, gardeners in the United States logged on to buy seed of a tomato unlike any sold before: purple to the core, as dark inside as a jamun fruit, its pigment borrowed from a snapdragon flower. Half a world away, in trial plots and terrace gardens across India, tomatoes with sun-blackened purple shoulders — bred entirely by conventional crossing — were already ripening beside the familiar red. Between these two fruits lies one of the most instructive stories in modern vegetable breeding: how scientists read the hidden colour code of the tomato, found the missing pages in its wild relatives, and rewrote the crop's oldest identity.

THE COLOUR CODE OF A TOMATO

Every tomato colour traces back to three pigment families. Carotenoids supply the warm shades: lycopene paints the flesh red, beta-carotene paints it orange. Flavonoids in the peel — chiefly the yellow compound naringenin chalcone — lay a golden film over that flesh; red seen through yellow gives the classic scarlet fruit. The third family, the anthocyanins, colour brinjal, black grapes and jamun in purple and blue — but cultivated tomato fruit makes essentially none. That single missing pigment family is the gap the last two decades of breeding have closed.

Switch any one pathway on or off and the fruit changes costume. Break the first gene of lycopene synthesis (psy1) and the fruit ripens yellow. Silence the peel regulator SlMYB12 and the colourless skin over red flesh reads as pink — the shade that commands the fresh markets of Japan and China. Let the fruit keep chlorophyll after ripening (the green flesh mutation) and green over red gives the smoky 'black' of heirlooms like Black Krim. Figure 1 maps the full palette, pigment by pigment, gene by gene.

PURPLE FROM THE WILD: BREEDING WITHOUT BORDERS

The purple story begins not in a laboratory but on the slopes of the Andes and the lava fields of the Galapagos. Wild tomato relatives there carry what the cultivated crop lost: genes that switch

on anthocyanin in the fruit skin wherever sunlight strikes. Two of these factors were brought into cultivated tomato by classical introgression — Anthocyanin fruit (Aft) from Solanum chilense and atroviolacea (atv) from Solanum cheesmaniae — and sat quietly in breeding collections for decades, each modest on its own.

The breakthrough was combinatorial. At Oregon State University, Professor Jim Myers and his students stacked Aft and atv into one background, and the two genes multiplied each other's effect. The variety released in 2011 as 'Indigo Rose' set fruit that turned near-black purple on every sunlit surface, ripening to purple over red — the first commercial tomato a consumer would honestly call purple, and every step of it conventional breeding. A whole 'Indigo' family followed. Because no foreign DNA is involved, these varieties face no biosafety regulation anywhere: any Indian breeder or grower may work with them today.

Their limitation: the anthocyanin stays in the skin, and the flesh within remains red. Pigment through the whole fruit demanded a bolder move.

THE SNAPDRAGON SWITCH: A TOMATO PURPLE TO THE CORE

Tomato is not missing the machinery to make anthocyanin — every gene of the pathway is present, merely silent in the fruit. In 2008 Professor Cathie Martin's group at the John Innes Centre, UK, woke that machinery with two master-switch genes from snapdragon, Delila and Rosea1. Expressed in fruit, the pair turned on the tomato's own pigment factory in every cell. The fruit that resulted was purple from skin to seed cavity, with anthocyanin concentrations rivalling blackberry and blueberry — and in the study that announced it, cancer-prone mice fed these tomatoes lived significantly longer than mice fed red ones.

Five years later came the finding no one had planned. Purple fruit ripened more slowly after harvest and shrugged off grey mould (Botrytis), roughly doubling shelf life — the anthocyanin was acting as an in-built preservative. For a crop whose post-harvest losses in India routinely run into double digits, that result reads less like a curiosity and more like a signpost.

Because it carries snapdragon genes, this is a genetically modified crop, regulated country by country. The United States cleared it in 2022, and in 2024 its seed went on open sale to American home gardeners — among the first GM food crops ever marketed to the public for a consumer benefit rather than a farm trait. It has no approval in India and is not available here; any future entry would

THE SCIENCE IN A NUTSHELL

- Red = lycopene; orange = beta-carotene; yellow = carotenoid pathway switched off; pink = colourless peel over red flesh; black/green = chlorophyll retained; purple = anthocyanin, the berry pigment tomatoes normally never make in fruit.
- Purple-skinned tomatoes (Indigo types) carry two genes from wild relatives, stacked by ordinary cross-breeding. Purple-fleshed tomatoes carry two snapdragon regulator genes and are genetically modified.
- Colour is visible chemistry: each shade advertises a different nutritional profile.



READING THE RAINBOW

Colour	Example varieties	Genetic basis	What it signals
Red	Pusa Ruby, Arka Vikas	Intact carotenoid pathway	Lycopene, the classic antioxidant
Orange	Caro Red types	Beta (B) or tangerine (t)	Beta types: provitamin A
Yellow	Golden Jubilee	psy1 loss of function	Mild flavour, low acid image
Pink	Momotaro, Pink Girl	SlMYB12 off in peel (y)	Premium fresh-market shade in East Asia
Purple skin	Indigo Rose family	Aft + atv (wild-derived)	Skin anthocyanin; non-GM
Purple flesh	Purple Tomato (USA)	Del + Ros1 (snapdragon; GM)	Berry-level anthocyanin; longer shelf life
Green / black	Green Zebra, Black Krim	green flesh (gf) retained chlorophyll	Heirloom flavour identity

Table 1. The tomato colour palette: varieties, genes and what each shade means at the table.

pass through our biosafety framework. Figure 2 traces the full timeline from heirloom to headline.

Colour is chemistry made visible. A mixed basket of red, orange, pink and purple fruit is not a novelty display — it is a portfolio of distinct antioxidant and vitamin profiles, harvested from one crop. Beta-carotene-rich orange types speak directly to vitamin A nutrition, still a live public-health concern for Indian children; anthocyanin-rich purple types bring to the daily curry the same pigment class that gives berries their health reputation.

WHAT THIS MEANS IN AN INDIAN FIELD

Speciality tomatoes fit precisely the channels growing fastest in Indian horticulture: urban retail, hotel and restaurant supply, farm-to-home subscription boxes, agri-tourism. Mixed-colour cherry tomatoes already fetch two to four times the wholesale price of ordinary fruit in metro markets, and the purple Indigo types — firm, striking, and unregulated — are natural candidates for polyhouse cultivation, where high light gives superb skin colour. Kerala, with its homestead-garden tradition and discerning urban consumers, is arguably better placed for this niche than any large-volume production state.

FIVE THINGS TO CHECK BEFORE YOU GROW COLOURED TOMATOES

1. Adaptation first: trial any exotic variety one season against local humidity, heat and day-length before scaling.

2. Bacterial wilt: Kerala soils are unforgiving; graft susceptible varieties onto resistant rootstock or grow in soilless bags.

3. Light drives purple: Indigo-type skin colour develops only on sun-exposed fruit; prune and train for light penetration.

4. Market before seed: secure a buyer — retailer, chef, or box scheme — before planting a niche colour at scale.

5. Educate at the point of sale: a shelf card explaining the pigment story converts curiosity into repeat purchase.

THE PRECISION ERA

Colour breeding is now entering its exact phase. With the tomato genome sequenced and nearly every colour gene identified, breeders stack shades into locally

adapted, disease-resistant backgrounds using DNA markers rather than guesswork. Genome editing has already recoloured tomato in research laboratories by rewriting the plant's own genes — no foreign DNA required — and the coming decade will treat pigment profile as a designed trait, specified the way we now specify yield or firmness. The tomato's next colour will not be found. It will be chosen.

From an Andean hillside to a snapdragon petal to a Kerala kitchen garden, the road from red to blue is a reminder of what plant breeding fundamentally is: reading the diversity nature has already written, and editing it into the food on our plate.

FIGURES

Figure 1. How genes paint the tomato — fruit colour, pigment chemistry and the underlying gene, with example varieties

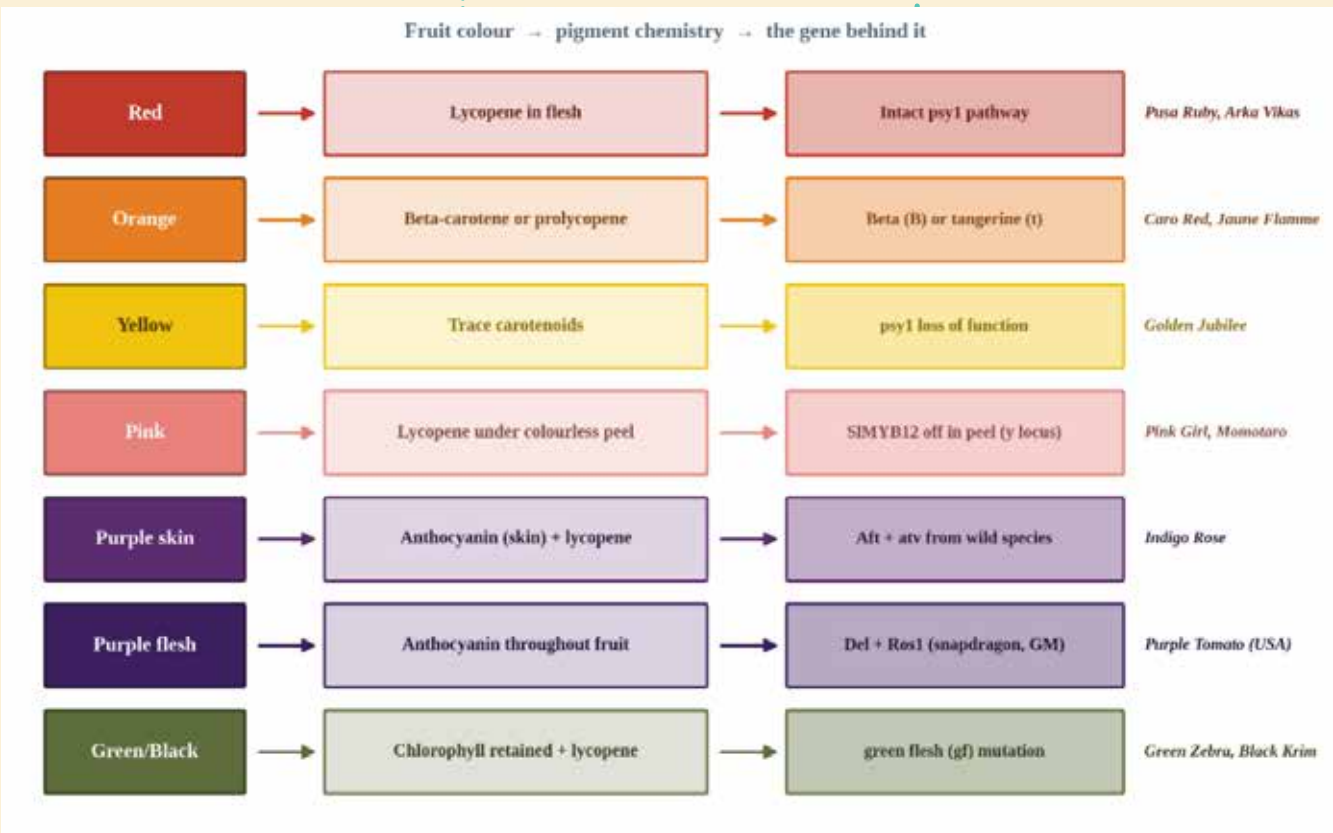
References

Butelli, E., Titta, L., Giorgio, M., Mock, H.P., Matros, A., Peterek, S., Schijlen, E.G., Hall, R.D., Bovy, A.G., Luo, J. and Martin, C. (2008). Enrichment of tomato fruit with health-promoting anthocyanins by expression of select transcription factors. Nature Biotechnology, 26: 1301–1308. https://doi.org/10.1038/nbt.1506

Zhang, Y., Butelli, E., De Stefano, R., Schoonbeek, H.J., Magusin, A., Pagliarani, C., Wellner, N., Hill, L., Orzaez, D., Granell, A., Jones, J.D.G. and Martin, C. (2013). Anthocyanins double the shelf life of tomatoes by delaying overripening and reducing susceptibility to gray mold. Current Biology, 23: 1094–1100. https://doi.org/10.1016/j.cub.2013.04.072

Mes, P.J., Boches, P., Myers, J.R. and Durst, R. (2008). Characterization of tomatoes expressing anthocyanin in the fruit. Journal of the American Society for Horticultural Science, 133: 262–269. https://doi.org/10.21273/JASHS.133.2.262

Ballester, A.R., Molthoff, J., de Vos, R., Hekkert, B.T.L., Orzaez, D., Fernandez-Moreno, J.P., Tripodi, P., Grandillo, S., Martin, C., Heldens, J., Ykema, M., Granell, A. and Bovy, A. (2010). Biochemical and molecular analysis of pink tomatoes: deregulated expression of the gene encoding transcription factor SlMYB12 leads to pink tomato fruit color. Plant Physiology, 152: 71–84. https://doi.org/10.1104/pp.109.147322





POLICIES OF POLLUTION

GLOBAL PROMISES, NATIONAL REALITIES, AND THE LONG ROAD TO CLEANER AIR, WATER, AND SOIL

Ms.Elsa Abraham[1] and Dr. Gowri Priya[2]

[1] B.Sc. (Hons.) Agriculture Graduate, College of Agriculture, Vellayani, Kerala Agricultural University

[2] Assistant Professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, Kerala Agricultural University

The Periyar river, which winds through the industrial corridor of Ernakulam in Kerala, was once a lifeline - drinking water, fish, livelihoods. Today, stretches of it run with effluents from chemical factories, and the fishermen who depended on it speak of a river they no longer recognise. Thousands of kilometres away, in the Czech Republic, Jana Dvořák describes the same quiet grief: "We stopped letting our children swim in it fifteen years ago. Nobody came to fix it. Nobody was held responsible."

These are not isolated tragedies. Across six continents, communities are living downstream, literally and figuratively, from industries that pollute freely, governments that regulate slowly, and policies that look bold on paper but collapse in practice.

So what does effective pollution policy actually look like? What have the world's major frameworks set out to achieve and how much has actually been delivered?

THE SCALE OF THE PROBLEM

Pollution is not a future threat. It is a present emergency. According to the World Health Organization (WHO), air pollution alone kills approximately 7 million people every year, which is more than AIDS, malaria, and tuberculosis combined. Soil and water contamination affect billions more, quietly poisoning food supplies and drinking water in ways that rarely make headlines.

The sources are well known: industrial manufacturing, fossil fuel combustion, agricultural runoff, plastic waste, and vehicle emissions. What is less understood is why, given this knowledge, policy responses remain so fragmented and so weak.

GLOBAL POLLUTION POLICIES: GOALS, GAINS, AND GAPS

Over the past five decades, the international community has attempted to bring pollution under collective control through a series of binding and non-binding agreements. Each represented a milestone. None has been fully delivered upon.

THE PARIS AGREEMENT (2015)

Goal: Limit global temperature rise to 1.5-2°C above pre-industrial levels by achieving net-zero greenhouse gas emissions by mid-century. Each signatory nation submits Nationally Determined Contributions (NDCs) - pledges to reduce emissions.

What was achieved: 196 nations signed the agreement, representing near-universal participation. Renewable energy deployment has accelerated globally, and several major economies , including the EU, UK, and Japan , have enshrined net-zero targets in law.

The stumbling blocks: NDCs are voluntary. There is no legal mechanism to compel compliance. A 2023 UN analysis found that if current pledges were fully implemented, the world would still be on track for 2.5-2.9°C of warming ,well above the 1.5°C target. The United States' withdrawal under one administration and re-entry under another exposed the fragility of political commitment.

THE STOCKHOLM CONVENTION ON PERSISTENT ORGANIC POLLUTANTS (2001)

Goal: Eliminate or restrict the production and use of twelve highly toxic chemicals, the "dirty dozen" , including DDT, dioxins, and PCBs, which persist in ecosystems and accumulate in the food chain.

What was achieved: Ratified by over 180 countries, the Convention has successfully banned most of its original target chemicals. Concentrations of several POPs have measurably declined in human tissue and wildlife across monitored regions.

The stumbling blocks: The list of regulated substances has been slow to expand. Many newly developed industrial chemicals with similar properties escape regulation for years before being added. In developing nations, enforcement infrastructure is often absent.

THE MINAMATA CONVENTION ON MERCURY (2013)

Goal: Phase out mercury-added products, control mercury emissions from coal combustion and industrial processes, and remediate contaminated sites, named after the Japanese city devastated by industrial mercury poisoning in the 1950s.

The stumbling blocks: Artisanal gold mining - one of the largest sources of mercury pollution, has proven extremely difficult to regulate, particularly in remote regions of Sub-Saharan Africa and Latin America.

EMISSION REDUCTION POLICIES: THE FRONTLINE OF THE FIGHT

Emission reduction sits at the heart of modern pollution policy. Three approaches have shown the most promise and revealed the most friction.

Cap-and-Trade Systems. The EU Emissions Trading System (ETS), launched in 2005, is the world's largest carbon market. Polluters are given a cap on emissions and can trade allowances with others. Over time, the cap tightens. The system has delivered measurable reductions in power sector emissions, down over 40% since 2005, but has

been criticised for setting initial caps too generously, allowing industries to profit without cutting pollution.

Carbon Taxes. A direct tax on carbon emissions, championed by economists as the most efficient tool. Sweden introduced a carbon tax in 1991; its emissions have fallen significantly while its economy has grown. Canada's federal carbon price, introduced in 2019, covers all fossil fuel combustion. The political challenge is stark, carbon taxes are visible to consumers and easy to campaign against, as France's 'Yellow Vest' protests demonstrated.

Vehicle Emission Standards. The EU's Euro standards, progressively tightened since 1992, have dramatically reduced nitrogen oxides and particulate matter from vehicles. India's Bharat Stage (BS) emission norms, modelled on the Euro system, leapt from BS-IV to BS-VI in 2020, bypassing an intermediate standard. Studies show this single step has reduced vehicle NOx emissions by up to 68% in tested models.

NATIONAL POLICIES: THE VIEW FROM INDIA

India presents one of the most complex pollution governance challenges in the world, home to 14 of the 20 most polluted cities globally, yet also the site of some of the most ambitious recent policy action.

National Clean Air Programme (NCAP, 2019). Goal: Reduce particulate matter (PM2.5 and PM10) concentrations by 20-30% in 122 non-attainment cities by 2024, with a revised target of 40% reduction by 2026. Progress has been uneven, some cities like Varanasi and Agra have seen improvements, while others remain far above safe limits. Critics point to weak monitoring networks and insufficient funding as key barriers.

Water Pollution - The Ganga and Beyond. The Namami Gange Mission, launched in 2014, allocated over ₹20,000 crore for the rejuvenation of the Ganges, India's most sacred and most polluted river. Sewage treatment capacity has improved in several towns. Yet industrial discharge, untreated municipal waste, and agricultural runoff continue to compromise water quality. The pattern repeats across the country. In Punjab, heavy pesticide and fertiliser use in the agricultural heartland has severely contaminated groundwater, with studies reporting alarmingly high nitrate and arsenic levels in villages of Malwa - a region now associated with unusually high rates of cancer, locally called the "cancer belt." In Maharashtra, the Ulhas river near Mumbai receives untreated effluents from over 700 industries, making it one of the most polluted rivers in the state despite years of court-ordered clean-up drives. In Tamil Nadu, industrial clusters around Tiruppur , the knitwear capital , discharged textile dye effluents into the Noyyal river for decades, devastating downstream agriculture and prompting the Supreme Court to order factory closures in 2011. The Periyar in Kerala tells a similar story: decades of effluents from the Eloor industrial belt have made it one of India's most contaminated rivers, despite repeated legal interventions by the Kerala High Court.

The stumbling blocks in India: Enforcement remains the Achilles heel. India has a robust legislative framework - the Environment (Protection) Act, the Air Act, the Water Act - but implementation is hampered by understaffed pollution control boards, poor real-time monitoring, and political reluctance to penalise large industrial employers.

THE POLICY LANDSCAPE GLOBALLY: WHAT WORKS

Where policies have genuinely worked, they share common features.

Clear, enforceable standards. London's Ultra Low Emission Zone (ULEZ) - tied to specific, time-bound targets with real financial penalties - reduced nitrogen dioxide by 46% in central London within a year of launch.

Polluter pays principle. When industries bear the financial cost of the pollution they generate-through carbon taxes, remediation levies, or strict liability - frameworks incentives to clean up shift fundamentally.

Community-level monitoring. Citizens equipped with real-time data become the most effective enforcement mechanism. Low-cost air quality sensors in cities like Beijing and Delhi have driven accountability where formal inspections have failed.

Cross-border cooperation. Pollution does not respect national boundaries. The EU's success in reducing trans boundary acid rain through binding Gothenburg Protocol targets offers a model for regions where rivers, winds, and ocean currents carry pollution across borders.

THE HUMAN COST OF INACTION

Behind every policy gap



is a human story. In Lagos, children in low-income neighbourhoods have blood lead levels that would trigger a public health emergency in Europe. In the industrial belt of Jharkhand, India, communities report cancer clusters near unregulated mining operations. In California's Central Valley, farmworkers breathe air that regularly exceeds federal safety limits, yet enforcement actions remain rare.

These are not accidents. They are the predictable outcome of systems that treat pollution as an acceptable cost of economic growth, and that consistently place that cost on the shoulders of those least able to fight back.

A WAY FORWARD

The solutions are not mysterious. The science is settled, the policy models exist, and the economic case for action - when long-term health costs, lost productivity, and climate feedback loops are counted - is overwhelming.

What is missing is political will, equitable enforcement, and the recognition that pollution policy is not an environmental issue separate from everything else. It is a public health issue, an economic issue, a justice issue, and a question of what kind of world we are willing to leave behind.

The Periyar did not turn grey overnight. Neither did Jana's river. And they will not run clear overnight either. But they can, if the policies we write finally match the promises we make.

References

1. *World Health Organization (WHO). Air Pollution. https://www.who.int/health-topics/air-pollution*
2. *IQAir. Air Pollution Kills 7 Million Every Year. https://www.iqair.com/us/newsroom/air-pollution-kills-7-million-every-year*
3. *United Nations Environment Programme. The Minamata Convention on Mercury. https://www.mercuryconvention.org*
4. *IPEN. Stockholm Convention on Persistent Organic Pollutants. https://ipen.org/policy/stockholm-convention*
5. *European Commission. The European Green Deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en*
6. *European Commission. EU Emissions Trading System. https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en*
7. *London City Hall. Ultra Low Emission Zone (ULEZ). https://www.london.gov.uk/programmes-strategies/environment-and-climate-change/pollution-and-air-quality/ultra-low-emission-zone-ulez-london*
8. *Ministry of Environment, Forest and Climate Change, Government of India. National Clean Air Programme (NCAP). https://moef.gov.in*
9. *National Mission for Clean Ganga. Namami Gange Programme. https://nmcg.nic.in*
10. *Kerala State Pollution Control Board. Periyar River Pollution - Status Report. https://www.keralapcb.kerala.gov.in*
11. *UN Climate Change. NDC Synthesis Report 2023. https://unfccc.int*

Department of Agriculture Development &
Farmers' Welfare
Farm Information Bureau

കേരളകർഷകൻ



Out Now!