Ministry of External Affairs
NEST Division

Emerging Technologies in Agriculture: Realizing the Export Potential of India's Agricultural Produce

Synopsis

Despite being one of the largest producers of food grains, vegetables and fruits in the world, India has remained at the lower end of the global agriculture export value chain as majority of the exports are low value, raw or semi-processed. To a greater extent this is attributable to the lack of uniformity in quality and standardization, cumulative losses across the agricultural value chain and the inadequacies and inefficiencies in the infrastructure. Also considering the constraints pertaining to land and water resources, it is prudent for the Indian agricultural sector to adopt efficient farming practices and techniques in order to increase productivity and reduce post-harvest losses.

Emerging Technologies (ETs) such as Internet of Things (IoTs), Big Data Analytics, Artificial Intelligence, Unmanned Aerial Vehicles (UAVs) and Blockchain are finding path breaking applications to improve yield, help in crop selection, efficient utilization of resources, monitoring crop growth, monitoring the parameters of soil health, and also in optimization of storage and time-sensitive local, regional, national and international agricultural supply chains. Against this backdrop, the paper discusses some of the prime use cases of IoTs, UAVs and Blockchain in agriculture such as precision agriculture, quality assurance in agriculture supply chains, crop monitoring, crop health assessment, traceability and smart contracts etc., highlighting the broad spectrum of their human-centric benefits on account of improved situational awareness and informed decision-making, agility, improved quality of the produce, efficient utilization of resources, better price realization, transparency, trust, inbuilt incentives for sustainable agricultural practices, and ease of compliance with regulatory requirements.

The paper also underscores the barriers to the commercialization and wide-scale deployment of ETs in the Indian agriculture sector, which traverse under-capacity, affordability for farmers with smaller landholdings, connectivity in the rural areas, lack of international standards for ETs, and risks of data and cyber security. The paper highlights the pivotal role of Cooperatives in overcoming some of the barriers to the implementation and adoption of ETs, enabling the mobilization of people and necessary resources, and reducing the deployment and operational costs to farmers with small landholdings. In addition to harnessing the power of collective action, Cooperatives can also facilitate in providing better scalability to technology solutions and market-base to technology developers, invigorating commercialization of ETs in the Indian agriculture sector.

Noting that India's share in the global agricultural exports stands at just around 2%, the paper throws some light on the strategic imperatives of elevating India's agricultural exports. It calls attention to leveraging ETs in agriculture to mitigate the emerging threat of climate change; efficient usage of ground water resources; minimize the risk of rejection of exports on account of high pesticide residue values; unleash the vast export potential of organically grown produce; increase export destinations and the share of high value commodities; and elevate the foreign exchange earnings of farmers as a result, also accelerating growth rate of the agricultural sector which is a significant contributor to India's economic development.

The Ministry of External Affairs can support this endeavour in no small measure, and therefore the paper calls for the active involvement of Indian missions abroad in exploring new markets for exports and prospects for expansion in the existing ones, facilitating exports, and disseminating critical information pertaining to food safety standards and regulations. Technology solutions built or deployed in India will also get traction in other developing and least developed countries with agrarian economies, and so will the corresponding commercialization models and capacities built.

The paper is purposed to be outcome-oriented. Towards the end, it maps some of the prominent private sector companies/start-ups from Australia, USA, France, UK, Israel, Japan, Poland, Canada, Spain as well as India engaged in the

development of IoT, UAV or Blockchain solutions for agriculture. This list could further be enriched with greater detail as and when required to. Moreover, in order to provide a broader picture, the paper lists the major importers of food and agricultural products in the international market, the top ten export destinations of agricultural products from India (2015-19), and the percent share of top five export destinations of agricultural products from India (2019-20).

I. Background

1. India is among the world's leading producers of agricultural and horticultural products. With around 2.4% of world's land and 4% of world's water resources, India's agricultural sector not just meets the domestic demand, which constitutes of around 18% of world's population, but also exports agricultural produce.[1] India's export of agricultural and allied products in 2020-21 stood at USD 41.2 billion, growing 17.5% over the previous year.[2] Major export destination of agricultural and horticultural produce and processed food from India include West Asia, Southeast Asia, South Asia, the EU, and the US.

2. The majority of agricultural produce in India is transacted through wholesale markets, but depending on the State and commodity farmers may sell directly to traders at the farm, to traders at markets, or directly to processors and cooperatives.[3] The onset of coordinated and structured supply chains mainly caters to the needs of exports and the high end domestic consumers where the quality and safety standards are higher. With the entry of organized retail, the 'farm-to-fork' model is also gaining traction in India by overcoming inefficiencies, shortening the supply chains and reducing costs. Moreover, consumers, both domestic and international, have become more interested in the origin of the food products,

[1] "Agriculture Export Policy", *Department of Commerce (Ministry of Commerce and Industry, Government of India)*, 2018, p. 6.
[2] "India's agriculture exports jump 17.34% to $41.25 billion in FY21", *Business Standard*, June 10, 2021, at https://www.business-standard.com/article/economy-policy/india-s-agriculture-exports-jump-17-34-to-41-25-billion-in-fy21-121061001623_1.html.
[3] "Training programme on Supply Chain Management in Agriculture", *National Institute of Agricultural Extension Management (Ministry of Agriculture, Government of India)*, at https://www.manage.gov.in/studymaterial/scm-e.pdf.

quality parameters and the farming practices, generating the need for traceability of agricultural products for these high end segments.

3. With the strategic objectives of diversifying India's export basket, boosting high value and value added agricultural exports, promoting the export of indigenous, organic and traditional and non-traditional agricultural products and increasing India's share in world agricultural exports, the Government of India introduced Agriculture Export Policy in December 2018.

4. The Policy also strives to enable farmers to export their produce and harness the abundant opportunities in overseas markets. Export of agricultural produce allows the farmers to earn higher prices for high quality produce. The Policy focuses on export oriented production, export promotion, better price realization for the farmers, and value addition to the sector through food processing.

5. Pointing out some of the structural deficiencies, the Agriculture Export Policy notes that India has remained at the lower end of the global agriculture export value chain as majority of the exports are low value, raw or semi-processed. Owing to the lack of uniformity in quality and standardization, and the cumulative losses across the value chain, horticultural produce looses on many export opportunities. Post-harvest, the inadequacies and inefficiencies in infrastructure, supply chain and cold chain management lead to losses somewhere around 8-18% of the value of produce.[4]

6. Agriculture is the source of livelihood for more than half of India's population. With scarce land and water resources, it is prudent for the agricultural sector in India to adopt the best farming practices and techniques and innovate continuously so as to increase productivity and optimally manage the harvest. Efficient agricultural marketing system and cost effective supply chain management are the key enablers of a vibrant agricultural economy; the former aims to provide remunerative prices to the producers and the latter ensures timely availability of commodities to consumers at reasonable prices.

[4] Refer footnote no. 1. Agriculture Export Policy, p. 6.

7. Technology is an integral part of the entire lifecycle of agricultural produce, right from crop planning and land preparation to the post-harvest activities which extend from the farm to the retailers' shelf. Digital technologies for data collection, storage, analysis, and sharing open up vast avenues for the implementation of Emerging Technologies (ETs) in both pre-harvest and post-harvest segments of the agricultural value chain. Some of the prominent ones which are finding path breaking applications in the agricultural sector include Internet of Things, Big Data Analytics, Artificial Intelligence, Unmanned Aerial Vehicles and Distributed Ledger Technology (Blockchain). To a greater extent, their implementation is enabled by the Internet, mobile technologies and devices, digitally-delivered services, apps and over the top platforms.

8. ETs can help improve productivity in agriculture and associated practices and address the structural deficiencies in post-harvest management of the produce. They could be helpful in improving yield, picking the right crop, efficient utilization of resources, monitoring crop growth, monitoring the parameters of soil health, and also in optimization of storage and time-sensitive local, regional, national and international supply chains.

II. Applications of Emerging Technologies in Agriculture

II (a). Internet of Things (IoT)

II (a) (i). Use cases of IoT in Agriculture

9. Precision Agriculture: IoT-enabled in-situ sensors and actuators can record and transmit real-time information regarding soil moisture and nutrient levels, provide localized weather forecasts, estimate water loss owing to evaporation, and control water flow for efficient irrigation. The data collected by these IoT devices can increase situational awareness and aid the farmers in decision making, such as to determine fertilizer requirements specific to the farm based on soil profiles, and ascertain the optimal plantation and harvest times.

10. Agriculture supply chains: IoT devices and applications are being utilised at a wider scale to monitor the movement of agricultural produce along the supply

chain. At the one end this ensures the quality and safety of the commodity, and at the other ends it enables traceability of the produce for the consumers and the sectoral regulators. IoT-based sensors are much more efficient in monitoring the condition of perishable items during storage or transportation and generating alerts if the parameters deviate from safe levels, avoiding spoilage and the ensuing losses.

(II)(a)(ii). Benefits of IoT in Agriculture

11. Informed decision-making: IoT-enabled agriculture allows farmers to monitor their farm land, crops and weather conditions in the real-time. Soil sensors for instance, can provide an accurate measure of vital parameters such as pH value, acidity, salinity and important nutrients such as Nitrogen, Phosphorous, and Potassium. Real-time information improves situational awareness, which eventually leads to informed decision-making.

12. Agility: Based on the inputs from IoT devices, real-time monitoring also helps in early prediction of issues and timely intervention as farmers can quickly respond to any significant change in weather conditions such as humidity, rainfall, temperature, soil parameters or the overall health of the crop. It could also be beneficial in saving crops from extreme weather events, which have become more frequent in the recent times.

13. Improved quality of the produce: IoT helps in collecting data on which analytics could be performed so that the decision-making in agricultural practices is data-driven. Better understanding of the local climatic conditions, soil quality and the dependencies thereof helps in increasing both the yield as well the quality of the produce.

14. Efficient Utilization of Resources: The data from IoT devices deployed in the field helps farmers to allocate the desired quantity of fertilizers or water at the right time for the optimum growth of the plants, increasing the utilization of resources and conserve the scarce ones. Such applications of IoT make agricultural practices

sustainable with efficient water usage based on soil moisture rather than pre-determined interval-based irrigation, and optimization of inputs and treatments.[5]

15. Quality assurance: Agriculture produce is perishable and its quality tends to deteriorate as soon as the produce leaves the farm. It is an arduous task to maintain and assure the quality of the produce. IoT devices can play an important role in monitoring the ambient temperature, humidity and other key factors which impact the quality of agricultural produce, and generate alerts for timely intervention in case any deviation in parameters is detected. The digital trail of these IoT devices could also stand as evidence of the quality of the produce maintained throughout the supply chain.

II (b). Unmanned Aerial Vehicles (UAVs)

II (b)(i). Use cases of UAVs in Agriculture

16. Soil and field analysis: UAVs can be instrumental at the beginning of the crop cycle to generate precise maps of the farm land for pre-planting soil health analysis and crop planning such as estimates of irrigation and fertiliser requirements.

17. Crop monitoring, health assessment and management: Monitoring crop over a vast farmland is a formidable challenge, further exacerbated by slope and elevation. Though satellite imagery offered a solution, but it has its own limitations on account of availability, costs, subjectivity to weather conditions and availability, and lack of precision. UAVs with remote-sensing (hyperspectral, multispectral, or thermal) payloads can generate high-resolution imagery as and when required to monitor plant growth and population and assess the health of the crop using vegetation indices, heat signatures or anomaly detection.[6] High-resolution and

[5] "IoT Applications in Agriculture", *IoT for All*, June 30, 2020, at https://www.iotforall.com/iot-applications-in-agriculture, and "How IoT Solutions for Indian Agriculture Are Working Despite Unique Challenges", *PrecisionAg*, September 21, 2020, at https://www.precisionag.com/digital-farming/how-iot-solutions-for-indian-agriculture-are-working-despite-unique-challenges/.

[6] "The Role of Drone Technology in Sustainable Agriculture", *PrecisionAg*, May 25, 2021, at https://www.precisionag.com/in-field-technologies/drones-uavs/the-role-of-drone-technology-in-sustainable-agriculture/

multispectral imagery can also help spot bacterial/fungal infections or infestations.[7] Equipped with this precise information, farmers can take corrective measure in time and focus resources on specific areas that need attention. As UAVs are capable of measuring distance and modulating their flight altitude as per the topography, they can scan the field and do targeted spraying with the correct amount of chemicals. The method is not just efficient and fast, but also reduces health risks and avoids excessive use of chemicals.

18. Precision Agriculture: In supporting precision farming, UAVs can do soil health scans, monitor crop health, spray fertilizers or pesticides, and assist in planning irrigation schedules and yield estimation. The spatial data from UAVs in conjunction with the field data from IoT devices can supplement analytics for improving farm productivity and providing actionable information.[8]

II (b)(ii). Benefits of UAVs in Agriculture

19. Optimize inputs: With the use of UAVs for precise mapping of the farmland, farmers can plan their crops well in advance and also estimate the quantities of inputs such as seeds, fertilizers and water etc. During the course of crop growth, UAVs could be utilized to spray the optimal quantities of fertilizers and pesticides/fungicides, reducing inputs costs for the farmers.

20. Increase in efficiency: UAVs increase efficiencies in the farming practices and techniques by reducing the need of human involvement in crop monitoring. UAVs can cover a large area in a given time span as opposed to manual monitoring. UAVs also prove to be efficient when used to spray fertilizers or chemicals. Moreover, as compared to satellite-based remote sensing, UAVs are cost-effective and they could be deployed readily as and when needed.

[7] "Six Ways Drones Are Revolutionizing Agriculture", *MIT Technology Review*, July 20, 2016, at https://www.technologyreview.com/2016/07/20/158748/six-ways-drones-are-revolutionizing-agriculture/

[8] Gerard Sylvester (ed.), *e-Agriculture in Action: Drones for Agriculture* (Food and Agriculture Organization of the United Nations and International Telecommunication Union: Bangkok, 2018), at http://www.fao.org/3/i8494en/i8494en.pdf.

21. Agility: In the eventualities of pest infestation and bacterial/fungal infection in the crop, UAVs aid farmers in timely detection and quick response to such threats, avoiding crop damage or failure. Real-time aerial monitoring of crop health using UAVs helps in early detection of issues and timely intervention, which is of essence in agriculture. Crop monitoring at a higher frequency is feasible with UAVs, increasing the agility of the farmers to respond to adverse events.

22. Reduce risks: Getting away with the need of manual spraying of pesticides and other chemicals on the crop, UAVs reduce the risks of health hazards to human beings. Moreover, UAVs also ensure optimal use of pesticides and chemicals on the crop, therefore reducing environmental risks arising from their rampant or ignorant use in agriculture.

II (c). Distributed Ledger Technology/Blockchain

II (c)(i). Use cases of Distributed Ledger Technology/Blockchain in Agriculture

23. Traceability/Supply chain provenance: The concern related to the safety and quality of food is common all across the globe. There is an increasing interest among consumers in both the domestic and international markets to know the origin of their food items, the farming practices at the point of origin, its safety (for example pesticide/chemical residues), and quality assurance along its movement in the supply chain. The demand for organic products is also rising constantly.[9] Distributed ledger technology/blockchain can provide participants all along the supply chain with data on provenance, production practices, transaction details, and product quality and safety, and regulatory compliance in a transparent manner. Given its design characteristic, blockchain can create and maintain an immutable digital record of every step in the agricultural supply chain, basically covering end-to-end journey of the produce from seed to consumption. At any step, the information related to every link in the supply chain, the producer, the place of origin, the shipping company, the destination, the transport, the warehouse and the

[9] Hang Xiong , Tobias Dalhaus , Puqing Wang and Jiajin Huang, "Blockchain Technology for Agriculture: Applications and Rationale", *Frontiers in Blockchain*, Vol. 3, No. 7, doi: 10.3389/fbloc.2020.00007.

retailer is readily available to every party involved in the supply chain for verification.[10] With blockchain, in a matter of seconds, retailers can track the origin of food and also verify whether the produce was grown under conditions specified or not, which could be a daunting task in the case of traditional food supply chain. Deployment of distributed ledger technology/blockchain in conjunction with IoT further removes the chances of human errors in data entry into the ledger.

24. Smart Contracts: One of the prime features of blockchain technology is Smart contracts. Built into the blockchain, Smart contracts are triggered when predetermined conditions are met. Smart contracts allow all participants in the supply chain to view the information stored on the blockchain. In agriculture, these could be implemented to ensure transparency in the procurement and payment process of farm produce. In the agriculture sector, Smart contracts can potentially insure a farmer's crops and make the claim process seamless, replacing the burdensome assessment-based insurance claim processes which could take up to a few months.[11] In the event of specific weather conditions, Smart contracts can trigger the damage claims automatically, easing the process for both farmers and insurers. It will be a much more effective solution if blockchain technology is implemented in conjunction with IoT and Geographic Information Systems.

II (c)(i). Benefits of Distributed Ledger Technology/Blockchain in Agriculture

25. Transparency: Supply chain provenance or traceability in the widely-spread and highly complex agriculture supply chains provide the much needed transparency not just to the consumer but also to the participants or the nodes in the supply chain. The immutable record of transactions in the distributed ledger could be accessed and verified at any step in the supply chain. It establishes the origin, journey and quality parameters of the produce, therefore reducing the likelihood of fraud and addressing safety concerns.

[10] "8 Blockchain Startups Disrupting the Agricultural Industry", StartUs Insights, at https://www.startus-insights.com/innovators-guide/8-blockchain-startups-disrupting-the-agricultural-industry/.
[11] Ibid.

26. Financial incentives: Given the visibility and access to key information enabled by blockchain technology to agricultural produce and commodities, there is a financial incentive or reward for the growers to engage in ecologically and economically beneficial farming and production practices.[12] Since consumers are increasingly seeking such information and basing their purchase decisions on it, they are likely to pay a premium which translates into increased earning potential for the farmers adhering to sustainable agricultural practices.

27. Trust: Availability of reliable information pertaining to the origin and assurance of quality basically fortifies the confidence of the customer in the specific agricultural produce or food item. From the producers' perspective, the use of blockchain technology helps build the reputation of their produce or products leading to brand building and loyalty. From the consumers' perspective, the concern pertaining to the safety, quality and environmental friendliness of the food items are addressed in a transparent manner using an immutable digital trail.[13]

28. Ease of compliance & quality control: Moving along the value chain, agricultural produce and commodities have to adhere to the standards of safety and quality laid by different regulatory bodies, both domestic and international. With critical information such as laboratory tests and chemical residues readily available for verification, blockchain could make the process of compliance with standards and quality control seamless and easy. To reap the maximum benefits blockchain should be implemented in conjunction with IoT devices deployed in the field measuring the key parameters of the soil.

[12] Refer footnote no. 7. *e-Agriculture in Action: Drones for Agriculture.*
[13] Refer footnote no. 8. "Blockchain Technology for Agriculture: Applications and Rationale".

III. ETs in Agriculture: Key Use Cases

	Function	Key use cases	ETs in use
Pre-harvest	*Crop Selection*: Demand and sale potential, budgetary requirements, decision based on climatic conditions and quality of the soil etc.	• Help producers increase yield, reduce input costs, and maximize profitability on per unit of cultivated land. • Analyze valuable insights from the data gathered from the fields, weather, and local climatic conditions to provide information like what to plant and where to plant a particular crop.	IoT AI Big Data
	Land Preparation: Choice and optimal use of fertilizers, layout and design of the field for efficient irrigation, seed selection based on price, water requirement, resistance to diseases, availability etc.	• Digital mapping the field and conduct pre-planting soil health analysis (macro and micronutrients, moisture and other factors) and crop planning such as to draw estimates of seeds, irrigation and fertiliser requirements.	UAVs AI Big Data
	Crop Monitoring: Density of sprouts/plants, monitor leaf size, crop color, disease symptoms etc, detection of plant diseases and pests, right time and the optimal quantity of fertilizers and pesticides to be applied, irrigation (timing & frequency) etc.	• Remote monitoring of crop health and early detection of health issues or signs of distress, infection and infestation. • Remote monitoring of soil health and determine the right time to apply fertilizers and water and their optimal quantifies. • Efficient and optimal usage of pesticides and chemicals and their remote application (spraying).	IoT UAVs AI
	Harvesting: Price information and forecasts, time of harvesting, quality assessment and grading	• Make price forecasts for the produce and assist in finding the optimal time of harvesting, so as to increase the benefits while retaining the quality.	AI Big Data Blockchain

	etc.	• Make quality and safety assessment of the produce at the time of harvest and maintain a digital record/proof of it, if possible at the farm-level. • Executing contracts, ensuring timely payment to the farmers (Smart Contracts) and maintaining record/proof the transactions.	
Post-harvest	*Storage*: Warehousing, Cold storage, preservation etc.	• Grading and safety assessment (residue levels) of the harvest with least human intervention, and maintain a digital record/proof of it. • Maintaining the quality of the produce and minimizing spoilage.	AI IoT Blockchain
	Logistics and supply chain management: Planning, optimization, retain quality, reduce spoilage etc.	• Planning optimal transportation routes and modes to reduce time consumption and costs. • Monitor the condition of produce, especially perishable items, as they move along the supply chain and maintain a digital record of it.	AI IoT Blockchain
	Traceability: Quality assurance, fraud detection, root cause analysis in case of rejections of a consignment.	• Provide accurate and reliable information regarding the place of origin of the food product/agricultural produce and its safety and quality parameters at any step in the supply chain. • Verify the journey of the commodity from the producer and place of origin to the retailer.	Blockchain

IV. Barriers to the Adoption of ETs in Agriculture

29. Capability: A vast majority of the farmers in India lack the desired skills to understand and learn the use of technology. Moreover, operating and maintaining electronics and digital systems requires local availability of the requisite capability. In general terms, the lack of awareness (digital literacy) and capability related to

the use of technology in agriculture is a major impediment in the deployment of advanced (or digital) technologies at a wider scale in India's agriculture sector.

30. High cost and affordability: Knowing that the lower levels of mechanization in India's agriculture sector are due to high costs of the farming equipment and smaller landholdings, the high cost of deployment could be a barrier to the adoption of ETs in the agriculture sector at a national-wide scale. The equipment needed to implement the IoT or UAV systems is quite expensive, or cost of developing, operating and maintaining applications that use blockchain technology is relatively high in terms of computational and human resources.[14] Small and marginal farmers may not have the capital outlay for the procurement of such equipment and that raises the question of affordability of ETs among the vast majority of farmers. Moreover, it would be a daunting task to calculate the return on investment generated by ETs and build a business case for their adoption looking at the long-term.

31. Connectivity: Weak telecommunication infrastructure in the rural and remote areas may not be able to support the quality of service of Internet connectivity required for the implementation of ETs, be IoT, UAVs or blockchain.

32. Standards: Owing to rapid development, international standards for ETs are underdeveloped and not mature yet. There are various competing proprietary platforms and frameworks in this space. Also, a lot of solutions and Proofs of Concepts related to the use ETs in agriculture are presently being developed for disparate use cases and are generally point solutions, rather than platforms. The absence of international standards for most of these technology areas can render the technology solutions and platforms non-interoperable, and also pose risks to privacy and security. Under such circumstances it would be difficult for the farmer to migrate from one solution to another, restricting the options and benefits arising out of market competition. The international efforts are ongoing in these areas, for example the ISO Technical Committee 307 on Blockchain and Distributed Ledger Technologies and other standardization efforts at ITU's Telecommunication Standardization Sector (ITU-T).

[14] Refer footnote no. 7. *e-Agriculture in Action: Drones for Agriculture.*

33. Scalability: There are many examples of start-ups engaged in building Proofs of Concepts and solutions for a specific use cases or limited to a geographical area (a specific crop/fruit, district, State or region). In order to reap the benefits of economies of scale, these start-ups/companies have to eventually expand their operations to the different parts of the country. Scaling of operations and technology solutions would require sustained funding, revenue streams and availability of skilled human resources in rural area or willing to work in rural areas.

34. Security: Once deployed, digital technologies in the expansive agriculture sector will certainly generate, gather and transact enormous amount of data. Technologies in the digital space have associated risks of data security and cyber security. Data protection and privacy is a major concern and the legal measures to prevent their abuse are being taken by countries and regions. The rising instances of data theft and cyber attacks may erode trust in digital technologies and impede wide-scale rollout of ETs in the agriculture sector.

V. The Role of Cooperatives in Adoption of ETs in Agriculture

35. Different estimates suggest that there is considerable loss of crop value between harvest and sale point in the developing countries on account of crop spoilage, poor planning, unreliable record keeping and lack of equipment. Small and marginal farmers cannot afford machinery or equipment to assist in the planting, growing and harvesting of crops. Moreover, they tend to rely on local middlemen for their finance/micro-finance needs and market access for their produce.

36. Cooperatives, which are run for and by local farmers, are a promising and well-tested solution to these inherent problems. Cooperatives harness the power of collective action (for example, to negotiate and provide better prices for production inputs such as seeds, fertilizers, fuel, and undertake transportation, packaging, distribution, and marketing of farm produce); create a platform for farmers to pool in resources (for example, machinery, equipment and land); provide access to

relevant information that can help farmers make informed-decisions (for example, selecting more profitable crops); and fulfil credit needs for working capital and investments.

37. Maximizing the benefits for its members, agricultural cooperatives have played a significant role in socio-economic development and poverty reduction. Farmers with small landholdings especially benefit from this access to resources, tools, and marketplaces. It is widely acknowledged that cooperatives can play an instrumental role in increasing farm yield and therefore the income of farmers.[15] Cooperatives in the agriculture, dairy and food processing sectors have been prevalent in India, whose origins are traced back to the first Cooperative Societies Act passed in 1904. Ever since then the cooperative movement has played an important role in the growth of Indian economy.

38. Cooperatives can encourage farmers to develop their farms and inculcate farming practices specific to the requirements of agricultural exports and achieve the economies of scale in the production and marketing of agricultural produce. Cooperatives can further help farms, specially the small ones, in overcoming the formidable challenge of compliance with the complex and frequently changing regulations in importing countries related to chemicals usage and residues and food safety etc. using prevalent techniques and technologies as well as with the use of ETs.

39. Cooperatives and Krishi Vigyan Kendras are best placed to increase digital literacy and spread awareness about the use of digital and emerging technologies in increasing farm yield, reducing input costs, optimizing resource allocation and getting better price realization through exports.

40. Cooperatives are pivotal to overcome some of the barriers to the implementation and adoption of ETs which are envisaged to support the production of export quality produce. It includes mobilization of people and necessary resources. Cooperatives can build the capacity required to operate and maintain electronics and digital systems at local, district, State and national levels.

[15] Refer footnote no. 7. *e-Agriculture in Action: Drones for Agriculture.*

41. Since high cost and affordability of ETs is a major impediment to their adoption, the pooling of resources or cost sharing spearheaded by cooperatives can reduce the deployment and operational costs substantially and make them affordable to farmers with small landholdings. With cooperatives in the central role, farmers do not need to make high upfront investments in ETs-based solutions, be its UAVs and IoT devices and platforms, or blockchain. Collective action can lower the costs and help farmers harness the real benefits of precision agriculture, crop monitoring and health assessment, traceability in the form of better decision-making, optimization of inputs, improved quality of the produce, greater compliance with international standards and higher price realization.

42. With a wider user-base, cooperatives can also provide better scalability and market-base to technology developers. Pan-India spread of cooperatives and similarities in their organisational structure and operations, Proofs of Concepts and solutions developed for a cooperative could easily be expanded to other districts, States and regions. This will enable the technology providers to harness economies of scale and bring the costs further down, which is mutually beneficial to the farmers and the technology developers.

43. There is vast network of cooperatives related to agriculture and associated activities in India, comprising of more than 6,000 societies operating at the primary and the district levels. Cooperative marketing federations function at the State and the National levels. Some of the successful examples of cooperatives in India include Amul, Indian Farmers Fertilizer Cooperative Limited (IFFCO), and Karnataka Milk Federation (KMF). From the point of view of implementation of ETs in the agricultural sector, it would be better to begin with cooperatives related to high value exports, tribal products and organics, working closely with state level federations and the Agricultural and Processed Food Products Export Development Authority (APEDA). Some of the cooperatives which could be considered are Indcoserve (Tea Co-operative Federation), Tribal Cooperative Marketing Development Federation of India (TRIFED), Mahagrapes, and Sahyadri Farms.

VI. Strategic Imperatives of Elevating India's Agricultural Exports & the Role of ETs

44. India is one of the leading exporters of agricultural products in the world, but India's share in the global agricultural exports stands at around 3.1%.[16] In order to elevate India's agricultural exports, the Agriculture Export Policy of 2018 aspires to provide a stable trade policy regime, diversify India's export basket, add new export destinations, boost high value products, tackle sanitary and phytosanitary issues, and integrate the output from the sector with global value chain.

45. The share of agriculture and allied sectors in India's GDP in 2020-21 stood at 20.2%.[17] The sector is estimated to grow at around 3% in the long run, which is significantly lower than the targeted GDP growth rate. Similar to the high growth witnessed by the services sector on account of increased exports, increase in agricultural exports will help elevate foreign exchange earnings and accelerate growth rate of the sector. Increased growth will certainly boost incomes in the agriculture sector, which employs about 45-46% of India's working age population.[18] In the long run, linking agricultural production to export markets will enhance income opportunities, ensure stability in farm income and invigorate overall economic growth.

46. In the agriculture sector, crop productivity, commodity prices and input costs are one of the critical factors which determine income. Owing to a number of factors such as supply chain inefficiencies, post-harvest losses, lack of availability and awareness in the use of modern agricultural practices and technologies, small landholdings etc, farm yield in India remains to be below the world average. Emerging Technologies can help improve productivity and efficiency, reduce input costs and spoilage, and therefore elevate export competitiveness of India's

[16] "India breaks into the top 10 list of agri produce exporters", *Mint*, July 22, 2021, at https://www.livemint.com/news/india/india-breaks-into-the-top-10-list-of-agri-produce-exporters-11626975654126.html.

[17] "Contribution of Agriculture Sector towards GDP", *Press Information Bureau*, August 03, 2021, at https://www.pib.gov.in/PressReleasePage.aspx?PRID=1741942.

[18] The World Bank, "Employment in agriculture – India", [based on data retrieved on January 29, 2021], at https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=IN, and "Share of agriculture sector in employment sees steady increase: CMIE", *The Economic Times*, August 12, 2021, at https://economictimes.indiatimes.com/news/economy/indicators/share-of-agriculture-sector-in-employment-sees-steady-increase-cmie/articleshow/85266073.cms.

agricultural produce and the products derived from it. The agriculture sector in India is witnessing a rise in the number of emerging agri-tech start-ups, such as Ninjacart, Agrostar, Stellops, CropIn, and Jumbotail. The use cases for ETs in India's agriculture sector are innumerable and the opportunities for their application are abundant.

47. Precision agriculture enabled by IoT and UAVs can help Indian farmers in soil health analysis, crop planning, and determining the right amount and time of application of fertilizers, nutrients and water based on prevailing soil parameters, crop monitoring and health assessment, identify bacterial/fungal infections or infestations, and also allow them to intervene timely to avoid crop damage or failure. Taken together as a whole, these measures can significantly improve the farm yield and lower the input costs.

48. Agriculture in India is vulnerable to the vagaries of weather. More than half of the net sown area in India is dependent on rains in the absence of irrigation infrastructure. This area accounts for around 40% of the total food production.[19] This specific issue is further compounded by the emerging threat of climate change, which could manifest in the form of erratic rainfall, frequent drought and flooding, unseasonal rainfall and other uncertain and adverse weather events. With the use of IoT and UAVs, precision farming can increase water utilization leading to highly efficient usage of water, especially ground water, which is a scarce and critical resource.

49. Improved supply chain efficiencies and logistics with the use of IoT and blockchain can curtail post-harvest wastage and losses on account of spoilage, and the ensuing savings in terms of quantity and costs can make Indian agricultural exports significantly competitive in the international markets. Perishable produce, around 40% of which is estimated to go to waste, is a prime use case here. During

[19] Press Information Bureau, "Land Under Irrigation", March, 05, 2020, at https://pib.gov.in/newsite/PrintRelease.aspx?relid=199881, and Rajni Jain, Prabhat Kishore, Dhirendra Kumar Singh, "Irrigation in India: Status, challenges and options", *Journal of Soil and Water Conservation* 18(4): October-December 2019, and "40% of India still banks on monsoon for agriculture", *The Times of India*, May 01, 2015, at https://timesofindia.indiatimes.com/india/40-of-india-still-banks-on-monsoon-for-agriculture/articleshow/47115057.cms.

storage or transportation IoT devices can help control or eliminate spoilage of perishables.

50. A major cause of concern for Indian agricultural exports is the pesticide and chemical residues. Exports from India have sometimes been rejected by importing countries due to residue values exceeding the Maximum Residue Limit.[20] The key to address this concern is judicious and timely use of chemicals and pesticides/fungicides/weedicides, and to replace the ones banned by the importing countries with alternatives. IoT devices deployed in the field help in determining the right quantity and time to use the chemicals and pesticides, while UAVs could ensure the application of right quantity. These measures can ensure quality control right at the farm level and minimize the risk of rejection of exported consignments considerably.

51. The use of blockchain allows participants in the agriculture supply chain to verify the origin, journey and quality parameters of the produce or product. Traceability, enabled by blockchain, could be handful in the case of rejection of exported consignments to conduct the root cause analysis and identify the reasons. Traceability can serve two purposes. First, it can enhance compliance of Indian agriculture sector with the global food quality and safety requirements and instil trust in the long term. Secondly, it can help garner loyalty of the consumers and establish Indian agriculture produce and food products with their own brand identity and brand value. Improved brand image will open up market for value added food commodities which have higher earning potential as compared to low-margin bulk exports.

52. Traceability will incentivize sustainable and ecologically beneficial agricultural practices and organic farming. As consumers are increasingly basing their purchase decisions on these considerations and willing to pay a premium, which translates into increased earning potential for farmers following such practices. Traceability will also unleash the vast export potential of organically grown produce such as herbs with known medicinal properties in the Indian Traditional Knowledge of Medicine (aloe vera, neem, turmeric etc.), nutraceuticals, spices, forest produce,

[20] Refer footnote no. 3. Agriculture Export Policy, p. 12.

tribal products, and healthy cereals. With traceability, value added organic produce, for instance, herbal medicine and formulations from the Indian Traditional Knowledge of Medicine, could be marketed for a premium generating higher earnings for the farmers/communities growing the ingredients or harvesting them from forests.

53. A wide variety of agricultural produce is grown in different parts of India. A key impediment in meeting the requirements of large export orders is the fragmented nature of farm production and lack of data aggregation platforms. It is also difficult to ascertain the current stocks available with different sources in different States. Though digitalisation of farm operations and agriculture supply chains can help overcome some of these, but supplemented by data from IoT, UAVs and analysis using AI and Big Data can help make accurate estimates of crop yield well advance in time, optimize harvesting time as per the demand, and reduce the time consumption from the 'farm' to the 'fork'.

54. In addition to fulfilling the domestic demand, Indian agricultural and horticultural produce and the associated processed food products are exported to more than 100 countries. The share of India's high value and value added agricultural produce accounts for less than 15% of India's total agricultural exports.[21] It is important that agricultural export basket is diversified by adding more export destinations and increasing the share of high value commodities (high value crops, processed food) in the export basket.

55. From future growth perspective, it is prudent to elevate the standards of farming in India with prevalent use of ETs so as to increase the exports to markets in the developed economies. It will also go a long way in strengthening the position of India's agricultural exports in the traditional markets and simultaneously explore new ones. In this endeavour, the active involvement of Indian missions is vital in exploring new markets for exports and prospects for expansion in the existing ones, facilitating exports, and disseminating critical information pertaining to safety standards and regulations.

[21] Refer footnote no. 3. Agriculture Export Policy, p. 8.

VII. List of some of the prominent private sector companies/start-ups in the ETs space:[22]

UAVs	Blockchain	Big Data	IoT
Measure Australia (Australia)	AgriDigital (Australia)	KG2 (Australia)	FarmMap4D Spatial Hub (Australia)
Agronomeye (Australia)	AgUnity (Australia)	AgDNA (Australia)	Telstra (Australia)
AeroVironment (USA)	FlashFX (Australia)	HP Enterprise (Australia)	CropLogic (Australia)
Parrot (France)	Everledger (Australia)	Monsandto (USA)	The Digital Homestead (Australia)
SenseFly (Switzerland)	UPS - Blockchain in Transport Alliance (USA)	FarmLogs (USA)	The Yield (Australia)
Zipline (USA)	Agriledger (UK)	AWhere (USA)	Conservis (USA)
PrecisionHawk (USA)	Everledger (UK)	DuPont Pioneer (USA)	Hortau (USA)
Delair Tech SAS (France)	Ripe.io (USA)	Iteris (USA)	John Deere Field Connect (USA)
Down2Earth Sensing (Netherlands)	Filament (USA)	Granular (USA)	FarmLogs (USA)
Avular BV (Netherlands)	IBM (USA)	Climate Corp (USA)	Pynco (UK)
Skyx (Israel)	SkuChain (USA)	Farmers Business Network (USA)	Cisco (USA)
Alta (Israel)	Walmart (USA)	ATP Lab (Israel)	Amazon Web Services (USA)
IAI (Israel)	Origin Trail (Slovenia)	Cropin (India)	Hitachi (Japan)
Dronitech (India)	Avenews (Israel)	Aibino (India)	Kontakt.io (Poland)
Indrones (India)	Agri1ox (India)		MotorLeaf (Canada)

[22] "Emerging Technologies in Agriculture: Consumer Perceptions around Emerging Agtech", *AgriFutures*, 2018, at https://static1.squarespace.com/static/57357678f8508265d38a4e72/t/5c89f2609140b7d7eeacc2d3/1552544443100/Emerging+AgTech+Consumer+Perceptions.

Ideaforge (India)			Libellium (Spain)
Aarav (India)			CropX (Israel)
			Fasal (India)
			QZense Labs (India)

VIII. List of major importers of food and agricultural products:[23]

S. no	Country	% of Word Total			
		1995	2005	2010	2017
1	USA	7.8	9.8	8.4	9.7
2	Germany	10.2	7.9	7.2	6.4
3	Japan	12.2	7.9	5.9	4.8
4	China	1.6	1.7	2.5	4.7
5	UK	5.6	6.3	5	4.4
6	Netherlands	5.2	4.3	4.3	4.7
7	France	6.6	5.4	4.8	4.3
8	Italy	5.1	4.6	3.9	3.3
9	Canada	2.2	2.6	2.6	2.6
10	Belgium	2.5	3.5	2.9	2.7
11	Spain	3.1	3.7	2.9	2.6

IX. Top ten export destinations of agricultural products from India (2015-19):[24]

S. no.	2015	2016	2017	2018	2019
1	Saudi Arabia	UAE	USA	Iran	Iran
2	USA	USA	UAE	USA	USA
3	UAE	Saudi Arabia	Iran	Saudi Arabia	Saudi Arabia
4	Iran	Iran	Saudi Arabia	UAE	UAE
5	Bangladesh	Bangladesh	Bangladesh	Bangladesh	China

[23] Ibid.
[24] "Major Export Partners", Food and Agriculture Organization of the United Nations, at http://www.fao.org/faostat/en/#rankings/major_partners_exports.

6	China	China	Viet Nam	Viet Nam	Bangladesh
7	Pakistan	Viet Nam	China	China	Nepal
8	Iraq	Nepal	Iraq	Nepal	Iraq
9	UK	Iraq	Nepal	Iraq	Netherlands
10	Viet Nam	UK	UK	Netherlands	UK

X. Percent (%) share of top five export destinations of agricultural products from India (2019-20):[25]

Floriculture	U S A (25.67%)	Netherland (14.50%)	Germany (7.56%)	U K (7.55%)	UAE (6.11%)
Fresh Onions	Bangladesh (23.71%)	Malaysia (18.71%)	UAE (12.80%)	Sri Lanka (12.64%)	Nepal (4.07%)
Other Fresh Vegetables	UAE (20.94%)	Nepal (18.32%)	U K (9.15%)	Qatar (8.80%)	Bangladesh (5.02%)
Walnuts	France (22.82%)	U K (19.20%)	Germany (18.23%)	UAE (17.08%)	Netherland (8.38%)
Fresh Mangoes	UAE (35.70%)	U K (16.89%)	U S A (7.64%)	Oman (6.89%)	Qatar (6.85%)
Fresh Grapes	Netherland (36.14%)	Russia (12.20%)	U K (9.44%)	Bangladesh (6.33%)	Germany (6.28%)
Other Fresh Fruits	UAE (21.81%)	Bangladesh (19.42%)	Iran (10.97%)	Nepal (10.49%)	Oman (6.04%)
Others (Betel Leaves & Nuts)	Sri Lanka (21.43%)	Maldives (18.39%)	Bangladesh (17.38%)	UAE (14.33%)	Nepal (7.39%)
Processed Vegetables	U S A (20.98%)	U K (10.38%)	Germany (7.15%)	Thailand (6.36%)	Russia (4.61%)
Processed Fruits, Juices & Nuts	Netherland (13.17%)	U S A (11.32%)	Saudi Arab (10.16%)	UAE (5.53%)	Russia (3.67%)
Pulses	China	U S A	Algeria	Bangladesh	Sri Lanka

[25] "APEDA AgriXChange", Agricultural & Processed Food Products Export Development Authority (Ministry of Commerce & Industry, Government of India), at http://agriexchange.apeda.gov.in/indexp/topfive_destination.aspx.

	(16.27%)	(13.32%)	(10.68%)	(10.57%)	(7.14%)
Buffalo Meat	Vietnam (33.39%)	Malaysia (11.83%)	Egypt (10.43%)	Indonesia (7.29%)	Iraq (5.33%)
Sheep/Goat Meat	UAE (70.25%)	Qatar (9.59%)	Kuwait (9.53%)	Saudi Arab (4.29%)	Oman (2.83%)
Other Meat	Bhutan (73.38%)	Vietnam (18.95%)	Myanmar (3.05%)	Nepal (1.66%)	Liberia (1.07%)
Processed Meat	Myanmar (32.29%)	UAE (23.71%)	Thailand (21.73%)	Qatar (12.10%)	Bhutan (5.61%)
Poultry Products	Oman (32.80%)	Maldives (11.59%)	Indonesia (8.00%)	Russia (7.28%)	Vietnam (6.89%)
Dairy Products	UAE (19.69%)	Bhutan (11.99%)	Turkey (9.77%)	Egypt (8.36%)	U S A (7.63%)
Albumin (Eggs & Milk)	Japan (37.81%)	Vietnam (28.72%)	Indonesia (11.85%)	Thailand (8.42%)	Philippines (5.17%)
Cocoa Products	U S A (24.43%)	Indonesia (10.53%)	Turkey (9.10%)	Nepal (5.56%)	Brazil (5.16%)
Cereal Preparations	U S A (17.72%)	Nepal (9.72%)	Bangladesh (7.60%)	UAE (7.29%)	U K (5.57%)
Milled Products	U S A (26.19%)	UAE (12.04%)	Qatar (7.37%)	Australia (7.12%)	U K (5.82%)
Alcoholic Beverages	UAE (31.88%)	Singapore (12.72%)	Netherland (6.81%)	Ghana (4.49%)	Nepal (3.15%)
Basmati Rice	Iran (28.51%)	Saudi Arab (21.88%)	Iraq (9.92%)	UAE (4.79%)	Kuwait (4.60%)
Non Basmati Rice	Nepal (12.08%)	Benin (9.58%)	UAE (6.48%)	Somalia (6.07%)	Guinea (5.96%)
Wheat	Nepal (72.06%)	Bangladesh (14.42%)	UAE (5.13%)	Somalia (2.33%)	DPR Korea (1.55%)
Maize	Nepal (67.96%)	Bangladesh (10.69%)	Myanmar (6.24%)	Pakistan (3.06%)	Bhutan (2.35%)
Other Cereals	Pakistan (13.52%)	UAE (13.01%)	Saudi Arab (7.56%)	Nepal (7.20%)	U S A (5.78%)

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