

Application of digital technologies in improving productivity and quality of pomegranate

Pomegranate (*Punica granatum* L.), is an ancient fruit crop with multiple health benefits. Its wide adaptability to different soil and climatic conditions has contributed to improvement in livelihood of small as well as marginal land holders. Although India is the global leader in pomegranate production; yet, it produces only 4% of its total produce. Hence, there is a lot of scope to increase the share of export, if productivity and quality of pomegranate can be enhanced. This can be achieved through application of sensors, drones and satellites in precision farming taking care of each and every individual plant. The advanced systems using Internet of Things can assist in connecting and monitoring the orchards. Deployment of artificial intelligence empowers data driven decision making, while that of blockchain technology ensures transparency and traceability. Application of robotics can streamline the automation of pomegranate cultivation for gaining efficiency and quality. At the end, all these technologies are available via mobile apps bringing information at the fingertips of pomegranate growers as well as consumers.

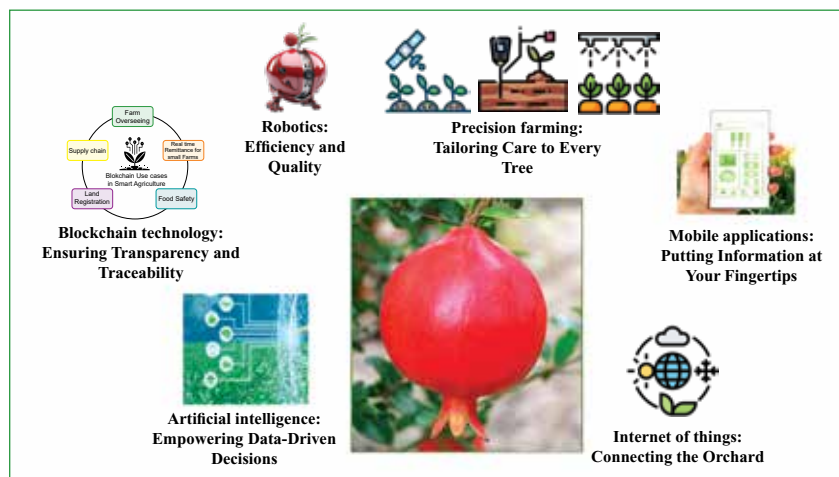
GLOBALLY, India is the second largest producer of horticultural crops, only behind China, accounting for more than 11% share of fruits and vegetables. One such economically important horticultural crop is pomegranate (*Punica granatum* L.) having a high adaptability to a wide range of weather and soil conditions, and therefore, is available throughout the year in India. It is mostly grown in Maharashtra, Karnataka, Andhra Pradesh, Gujarat and Rajasthan. Pomegranate from Solapur, Maharashtra is famous for its special characteristics and has been granted the Geographical Indication (GI) tag due to its appropriate geographical conditions, which contribute to production of good quality fruits naturally on a large scale. Both the climate and soil conditions of this region contributed to the uniqueness of pomegranate grown in Solapur district. Among the major fruit crops grown in India, from 2011-12 to 2019-20, pomegranate showed an increase of 152% in its area under cultivation surpassing grapes, banana, citrus, guava, and papaya. Consequently, the production of pomegranate increased by 312% during this period, which was also the highest amongst all the fruits. Though India is the largest producer of the pomegranate in the world, it exports only around 4% of its total produce. However, from 2011-12 to 2019-20, its export witnessed an increase of 167%, which was second only to increase in banana exports (329%). In terms of export value, in 2019-2020, India exported pomegranate for ₹6875 million showing an increase of 2.24% lagging behind grapes and apple. Thus, pomegranate plantation has played a very significant role in improving the socio-economic scenario of small land

holders (2.5 million).

Pomegranate production as well as post-harvest management faces several challenges, including biotic and abiotic factors. Bacterial blight (caused by *Xanthomonas citri* pv. *punicae*) and wilt (caused majorly by *Ceratocystis fimbriata*, *Fusarium* spp. and root knot nematode) are major diseases that can cause significant losses. Planting material that is multiplied through air layering or hard wood cuttings can carry diseases like nematode, bacterial blight, and wilt leading to spread of these diseases in the orchards. Major fungal fruit rots include anthracnose (caused by *Colletotrichum* spp.) and heart rot caused by *Alternaria* spp. Recently, some new pathogens have also been reported to infect pomegranate including *Lasiodiplodia theobromae* causing stem canker and *Calonectria hawksworthii* causing collar rot. Pests like fruit-sucking moth, fruit borer, and pomegranate butterfly can damage the fruit and reduce the yield and quality. The pomegranate butterfly, *Virachola livia* (Klug), can adversely affect the fruit juice quality. Fruits grown in areas with hot climates are more likely to get sunburned due to the increased exposure to solar radiation. Similarly, the probability of fruit cracking is higher in semi-arid areas, where it can reach 10–35%. Common causes associated with fruit cracking may be improper irrigation, environmental factors, and nutritional deficiency, especially boron, calcium, and potash.

Application of digital technologies

In the 20th century, agriculture became an



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amalgamation of farming practices and science/technology. In the 21st century, it is time to utilise digital technologies efficiently for enhancement of agricultural produce. Digital technologies are revolutionizing agriculture, including pomegranate cultivation. By 2050, lower number of people are expected to be involved in farming hence mechanisation in farm operations starting from planting to harvesting is the way forward. By leveraging data-driven acumens and automation, farmers can significantly improve yield, quality, and sustainability.

Precision farming: Precision farming, powered by data-driven insights, is a cornerstone of modern farming practices. In pomegranate cultivation, precision farming has contributed significantly in enhancing production through nutrient and water use efficiency. For example, variable rate fertilisation (VRF) is one of the central technologies of precision farming and can save phosphorous, potassium and nitrogen application as compared to conventional fertilisation. Another aspect of precision farming is precision irrigation. Since, pomegranate is adapted to arid or semi-arid conditions, excess of water is a waste of resources leading to increased inexpenses. At the biological level, excess of water can hamper the aeration of the roots which may cause fruit cracking, or attack by pests and soil-borne pathogens. Precision irrigation in pomegranate orchards thus helps in preventing moisture stress as well as fertiliser leaching. Frequent fertigation in sufficient volumes based on the growth stage of the plants is provided according to the depth of the root system. Through precision irrigation system, we can ensure that each plant receives just the right volume of water ensuring optimal hydration that promotes good health as well as better growth of each plant in the orchard.

Precision farming also involves the use of sensors, drones, and satellites to collect and analyse data about various factors affecting plant growth.

Sensors: Wireless Sensor Networks (WSNs) have a promising role in precision farming. These can be employed to precisely record and monitor real time weather; and soil and crop growth parameters. Due to changing climatic conditions, crops like pomegranate have suffered huge losses. Pomegranate is known to

be a crop for arid and semi-arid regions, however, due to unseasonal and erratic heavy rains in the past few years, the crop has faced heavy losses due to diseases such as bacterial blight which thrive well in humid conditions. In such a scenario, WSNs are being successfully deployed for monitoring soil and climatic conditions which can optimise water and fertiliser application and also help in management of diseases of pomegranate. Moreover, the data recorded by WSNs can be stored/shared over internet such that a database can be created based on which experts can provide advice to the growers. Similarly, based on the real time monitoring of environmental, soil, hydrological and crop related parameters by WSNs, agro-advisories is now provided to the farmers via SMS or email.

Unmanned ground vehicles (UGVs) equipped with visual sensors provide real-time information about the conditions surrounding pomegranate trees. Now sensors can be used to differentiate fruits from non-fruits areas. For such discrimination, sensors can be based on colour as well as shape of the fruit. These features help to differentiate between fruits and surrounding leaves and branches. Using sensors to monitor soil moisture, temperature, and nutrient levels helps optimize irrigation schedules and fertilization plans; pest control measures; reducing waste and improving fruit quality. Sensors can estimate yield potential, helping farmers informed about harvesting and marketing time.

Drones and satellites: Advancement in satellite-based image capturing has accelerated the use of remote sensing in precision farming. Further, the usage of unmanned aerial vehicles (UAVs), i.e. drones for midair photography to collect high-resolution spectral images has increased due to its cost-effectiveness and flexibility. With the help of UAV-imagery, a spatial and tree-by-tree distribution pattern of evapo-transpiration can be obtained accurately in pomegranate orchards. This is crucial for water management based on evaluation of soil moisture, drought and crop water stress. Similarly, accurate prediction and estimation of yield can be performed using UAV-based remote sensing methods. High resolution images acquired using UAVs and various features can be extracted which can be used to develop machine learning models for accurate prediction of fruit yield. Further, aerial imagery provides a comprehensive overview of orchards, allowing farmers to identify areas with stress, disease, or nutrient deficiencies enabling them to take targeted corrective actions.

Satellite-based remote sensing has application in precision farming cultivation because these data identify potential issues, such as nutrient deficiencies or pest infestations, long before they become visible to the naked eye. Hence, this can be used to monitor crop health well within time and assist in decision support system.

Internet of Things: The Internet of Things (IoT) is a network of physical objects that are connected to the internet and can communicate with other devices

and systems. IoT devices, equipped with sensors and connectivity, create a network that enables real-time monitoring and control of various aspects of pomegranate cultivation.

Smart irrigation systems: IoT-enabled systems can automatically adjust irrigation based on real-time weather and soil moisture data, ensuring efficient water usage by preventing overwatering and under-watering. In a comprehensive study that accumulated data over two years, a web-based irrigation decision support system was found to be effective in management of water resources for irrigation in Italian pomegranate orchards. An attempt is being made towards developing low-cost yet intelligent devices based on IoT that can be efficiently used as smart irrigation system.

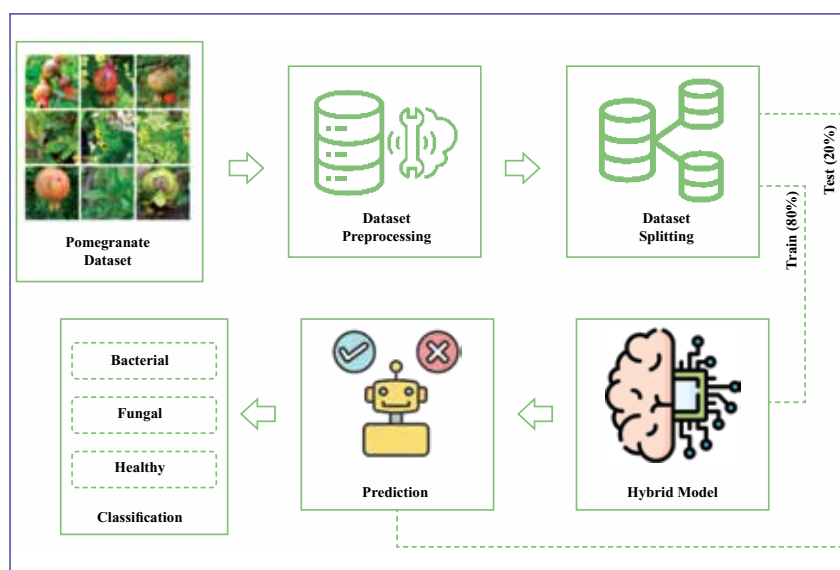
Pest and disease monitoring: IoT devices having sensors can detect early signs of pests and diseases, enabling timely intervention to prevent crop damage. Bacterial blight and Cercospora fruit spot are diseases that show early signs on leaves. IoT enabled pomegranate leaf disease detection and classification models based on Hidden Markov Model (HMM) have been developed, which could accurately determine pomegranate leaf diseases. Moreover, IoT based devices can be applied for monitoring soil, water and air quality, hence identifying conducive environment safe for pomegranate cultivation.

Image analysis using AI: AI algorithms can analyse images of pomegranate to assess their quality, detect defects, and predict ripeness ensuring that only the best fruits reach the market. K-means clustering has been widely applied for detection of bacterial blight on pomegranate fruits and training the model to differentiate between diseased fruits and healthy fruits. Various features such as fruit colour, shape and presence of spots on fruit surface can be extracted using Convolutional Neural Networks (CNN) and classes could be detected using Long-Short Term Memory (LSTM). In addition to disease detection, machine vision can also be utilised for detection of sunburn which causes dark brown colour on the fruits.

Using more robust algorithms for machine learning (ML) and deep learning (DL), classification models have been developed that can be used to classify images into more than two classes for example bacterial blight (Telya), anthracnose, fruit spot, Fusarium wilt, and fruit borer. NRCP in collaboration with NIT-Suratkal is working on developing models for such multi-class identification of bacterial and fungal disease.

Predictive analytics: Forecasting models developed on the basis of various parameters such as weather, soil and water parameters are beneficial for farmers. With the advent of artificial intelligence and machine learning in the recent times, these predictive models have achieved accuracy rates beyond expectations. Several micro-level parameters such as temperature, relative humidity, wind speed, wind pressure, precipitation, weather description, sunshine hours and soil moisture can be utilised to obtain a minimum error rate.

Weather-based prediction models become all the more important in an export-oriented crop such as pomegranate. Due to ever changing climatic conditions, bacterial blight which was a major constraint during rainy season crop (Mrig bahar) became a serious issue in winter season crop (Hast bahar) as well leading to losses up to 60% of the total produce. The favourable microclimate conditions if monitored accurately and prediction is made timely, then these losses can be averted. Several studies have been conducted at ICAR-NRCP indicated bacterial blight occurrence to be correlated with low night temperatures, high humidity, slight drizzles and extended number of rainy days. Day temperatures between 25 to 35°C and relative humidity of more than 30% were found to be conducive for blight appearance. Blight prediction models based on weather parameters are underway through collaboration between ICAR-NRCP and ICAR-CRIDA. In addition to biotic stress prediction, AI can be used for prediction of abiotic stress response of pomegranate trees as well. Hyperspectral reflectance can be used non-destructively to detect and monitor salt stress response of pomegranate cultivars. AI models can also predict future crop yields, market trends, and potential challenges, helping farmers make informed decisions.



Workflow of the proposed approach for multi-class classification of pomegranate fruits based on hybrid model being developed by ICAR-NRC on Pomegranate in collaboration with NIT-Suratkal

Blockchain technology for transparency and traceability

Fruit processing operations in pomegranate industry have the prospect to take advantage from Industry for ideas by refining traceability (leveraging blockchain), monitoring, and control of food quality (through improved IoT sensors); improving safety, manufacturing, automation; and reducing loss and waste through improved smart manufacturing lines. Blockchain technology provides a secure and transparent way to track the journey of pomegranates from the orchard to the consumer.

Traceability: Blockchain can trace the origin of each pomegranate from the orchard to the consumer, ensuring transparency such

that consumers can verify its quality and authenticity. For ensuring traceability in the export value chain of pomegranate, APEDA organizes sensitisation programmes on a regular basis in association with state governments to register farms under AnarNet – a system developed by APEDA. Further, INI farms, one of the leading farms in India have introduced features such as origin traceability for its individual fruits in international as well as domestic market under the technology-enabled program called 'Fruit Route'.

Supply chain management: Blockchain can optimize supply chain operations, reducing waste and the risk of counterfeits, thereby, ensuring food safety, and improving efficiency. A green, closed loop supply chain (CLSC) for pomegranate fruit based on the value chain can be implemented. A circular economy based on biochar, ethanol production and a type of compost processed as an organic fertilizer as a means of pomegranate waste management is a sustainable approach.

Robotics

Robotic systems can automate various tasks in pomegranate cultivation, reducing labour cost and improving efficiency.

Harvesting: For robotic harvesting in orchards, the first and foremost is fruit detection and localisation. Farmer robots equipped with camera that capture images in field can be trained to differentiate fruits from non-fruit regions. This allows easier and automated harvesting. However, the fruit detection methods often face challenges such as changes in illumination, shielding of leaves and branches, overlapping of fruits to name some. Generally, fruit detection is based on 2D image analysis, however, recent trends suggest the applicability of 3D images for the same. In addition, robots can be used for sorting and grading and thus, robotic harvesters can efficiently pick pomegranates, reducing labour costs and minimizing damage to the fruit.

Pruning and thinning: In future, as we face shortage of cultivable land, canopy structure of pomegranate plant is also bound to change from multi-stem to single stem shrub. This will not only make high density planting possible but also give way to mechanisation. Robotic

systems can automate pruning and thinning tasks, improving fruit quality and yield.

Mobile applications

Farming management: Mobile apps can provide farmers with real-time data, weather forecasts, and expert advice, making it easier to manage their orchards. Mobile apps can help farmers track crop growth, monitor weather conditions, and receive alerts about potential threats.

Market information: Apps can connect farmers with buyers and provide market price information. For example, AnarNet is an internet based electronic service offered by the APEDA to the stakeholders for facilitating testing and certification of pomegranate orchards for export from India to European Union in compliance with the standards identified by the National Referral Laboratory of ICAR-NRCG, Pune. Dalimbmitra is also an application wherein farmers can connect with pomegranate experts and get solution to their problems.

SUMMARY

Pomegranate is the mainstay of Indian horticulture sector yielding high monetary gains through exports. Although India has emerged as the global leader in pomegranate production, we are yet to fully utilise our potential in terms of export to global market. For better exports and even higher returns, digital technologies are revolutionizing the pomegranate industry by enhancing productivity, improving quality, and ensuring sustainability. By adopting these digital technologies, pomegranate growers can enhance productivity, improve quality, reduce cost, and ensure sustainable practices. They can also stay competitive in the global market and meet the increasing demand for high-quality, traceable fruits. As technology continues to advance, we can expect even more innovative solutions to emerge in the future.

For further interaction, please write to:

Dr Marathe R. A. (Director), ICAR-National Research Centre on Pomegranate, Solapur, Maharashtra 413 255. *Corresponding author: director.nrcpom@icar.gov.in

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For assistance contact:

Business Manager

Directorate of Knowledge Management in Agriculture (DKMA)
Indian Council of Agricultural Research
Krishi Anusandhan Bhavan-I, Pusa, New Delhi 110 012
Telefax: 011-2584 3657; E-mail: bmicar@gmail.com