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Artificial Intelligence in Fruit Crop Production: From Smart Orchards to Predictive Harvesting

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Fruit cultivation is one of the most important and economically valuable components of horticulture. Mango, citrus, apple, banana, grapes, guava, pomegranate, papaya, sapota and several other fruit crops provide food, nutrition, employment and income to millions of farmers. However, fruit production is becoming increasingly challenging due to labour shortages, rising input costs, climate variability, water scarcity, pest and disease outbreaks and increasing consumer demand for high-quality fruits. Traditionally, orchard management has depended heavily on the experience and observation of farmers and horticulturists. Decisions regarding irrigation, fertilization, plant protection, pruning, crop-load management and harvesting are often based on field observations and past experience. While this knowledge remains extremely valuable, the increasing complexity and scale of modern orchards require technologies capable of processing large amounts of information quickly and accurately. This is where Artificial Intelligence (AI) is emerging as an important tool in modern fruit science. AI refers to computer-based systems capable of analysing large quantities of information, identifying patterns, learning from previous data and assisting in decision-making. When combined with cameras, drones, sensors, satellites, robotics and mobile applications, AI can transform a conventional orchard into a smart orchard, where crop conditions can be monitored continuously and management decisions can be made with greater precision.

Artificial Intelligence in Fruit Production

In simple terms, Artificial Intelligence enables a computer system to learn from information and use that knowledge to make predictions or recommendations. For example, in a mango orchard, a farmer may visually observe that a particular block has a good crop. An AI-based system, however, can analyse drone or camera images to identify individual trees, flowers and fruits and combine this information with weather, soil-moisture and historical yield data to estimate expected production. AI can therefore help answer several important questions related to orchard management. It can indicate which trees may be experiencing water stress, identify areas where pest or disease problems are developing, estimate the number of fruits present on trees and predict likely yield. It can also assist in determining fruit maturity and the appropriate harvesting period. In this way, AI does not necessarily replace farmers or horticulturists; rather, it can function as a decision-support system that helps them make faster and more informed decisions.

From Conventional Orchards to Smart Orchards

A smart orchard is an orchard in which information from different sources is continuously collected and used to improve crop management. Sensors can monitor soil moisture, temperature, relative humidity and other environmental conditions, while cameras can capture images of leaves, flowers, fruits and the canopy. Drones and satellite imagery can provide information over larger areas, allowing farmers and horticulturists to identify variations within an orchard that may not be visible through ordinary field observations. The real advantage comes when these different sources of information are combined using AI. For example, if soil moisture decreases, temperatures increase and weather information indicates continued dry conditions, an AI system can assess the possibility of water stress and recommend irrigation. In advanced systems, this information can be connected to automated irrigation equipment so that water is supplied according to the actual requirement of the crop. This approach can shift orchard management from reactive decision-making to predictive and precision-based management.

Artificial Intelligence for Orchard Monitoring

One of the most practical applications of AI in fruit production is orchard monitoring. Large orchards may contain thousands of trees, making it difficult for farmers and field workers to inspect every plant regularly. Conventional monitoring generally involves inspecting selected trees and using these observations to represent the entire orchard, but this approach may overlook important variations between different areas. AI-powered cameras and drones can provide a much larger picture of orchard conditions. Images can be analysed to identify differences in plant vigour, canopy development, flowering intensity, fruit distribution, water stress and possible pest or disease symptoms. Computer vision and deep-learning technologies are particularly useful because they can be trained to recognize specific patterns in plant images. This can allow farmers to identify problem areas at an early stage and concentrate their field inspection and management efforts where they are most needed.

AI-Based Pest and Disease Detection

Pests and diseases are among the major factors responsible for yield and quality losses in fruit crops. Early identification is particularly important because timely intervention can prevent a localized problem from developing into a major outbreak. Traditionally, diagnosis depends largely on visual observation by farmers, field workers or experts, but symptoms of different diseases, nutrient deficiencies and environmental stresses can sometimes appear similar. AI-based image recognition offers an additional tool for disease diagnosis. A farmer could capture an image of a suspicious leaf or fruit using a smartphone and an AI model trained using disease images could compare the characteristics of the submitted image with previously identified symptoms. Such systems are increasingly being investigated for crop health monitoring and disease recognition. However, AI-based diagnosis should currently be considered a decision-support tool, particularly when symptoms are unclear and confirmation by trained experts may still be necessary.

Precision Irrigation through AI

Water management is becoming increasingly important in fruit production because fruit crops are generally perennial and water stress at critical stages can affect flowering, fruit set, fruit development and final fruit quality. Conventional irrigation schedules often follow fixed intervals, even though crop water requirements can change with weather conditions, soil type and growth stage. AI can combine information from soil-moisture sensors, weather stations, crop growth stages and historical irrigation records to estimate the water requirement of a fruit crop. Instead of applying the same amount of water throughout the orchard, irrigation can be adjusted according to the actual requirement of different orchard sections. Such precision irrigation can help improve water-use efficiency and reduce unnecessary water application, which is particularly important in water-limited regions.

AI for Flower and Fruit Counting

One of the promising applications of AI in fruit science is the automatic counting of flowers and fruits. The number of flowers and young fruits on a tree provides valuable information about potential crop load, but manual counting becomes extremely difficult when hundreds or thousands of flowers and fruits are present. Cameras mounted on drones, tractors or other field equipment can capture images of trees, which can then be processed using computer vision and deep-learning algorithms. The system can identify individual flowers or fruits and estimate their number. This information can support crop-load management decisions such as thinning and can also contribute to yield prediction. Recent research has demonstrated the growing potential of machine vision, deep learning and other intelligent technologies for automatic fruit detection and yield estimation in orchards (He *et al.*, 2022).

Predictive Yield Estimation

Yield prediction is one of the most commercially important applications of AI in fruit production. Traditionally, yield estimation involves counting fruits on selected trees, estimating average fruit weight and extrapolating the result to the entire orchard. Although this approach can provide useful estimates, it is labour-intensive and may not accurately capture the variability present across a large orchard. AI can analyse information from several sources, including fruit number, fruit size, canopy characteristics, vegetation indices, weather conditions, historical yield and crop management records. Machine-learning models can use these data to estimate the expected yield before harvesting begins. Recent research on machine-learning-based crop yield prediction demonstrates the increasing use of environmental, crop and historical production data to improve yield forecasting. Accurate yield prediction can help farmers plan labour requirements, harvesting schedules, transportation, storage and marketing more effectively.

AI for Fruit Quality Assessment

Yield is only one component of successful fruit production, quality is equally important because market price is strongly influenced by fruit size, colour, appearance, maturity, firmness and freedom from defects. Conventional quality assessment is often carried out manually, which can be time-consuming and may introduce differences between individual workers. AI-based computer vision systems can analyse fruit images and classify fruits according to their size, colour, shape and visible defects. More advanced sensing technologies, including hyperspectral and multispectral imaging can also be combined with AI to assess internal and external fruit characteristics. Hyperspectral imaging, in particular has received considerable attention as a non-destructive approach for evaluating quality characteristics in fruits and other horticultural commodities. Recent research has further highlighted the potential of AI and machine learning for rapid, non-destructive fruit quality assessment, including grading, defect detection and maturity evaluation (El-Beltagi *et al.*, 2026). Such technologies can improve the speed and consistency of fruit grading and help separate fruits into different market categories. High-quality fruits can therefore be directed towards premium markets, while lower-grade produce can be utilized for processing or other suitable purposes.

AI and Predictive Harvesting

Harvesting is one of the most labour-intensive operations in fruit production, particularly in crops where fruits do not mature uniformly. Harvesting too early can result in poor quality, while harvesting too late can lead to over-maturity, fruit drop and reduced market value. Determining the correct harvesting time is therefore critical. AI can assist in identifying fruits that have reached the appropriate stage of maturity by analysing characteristics such as colour, size, shape and other visual indicators. Cameras can monitor individual fruits, while AI algorithms can classify them according to their maturity stage. Research on fruit ripeness classification has demonstrated the potential of machine-learning approaches to automate maturity assessment and reduce the subjectivity associated with conventional methods. The concept becomes even more interesting when AI is integrated with robotic harvesting systems. A harvesting robot can potentially detect a mature fruit, determine its location, position its robotic arm, gently detach the fruit and place it into a collection container. Although this technology is still developing and several technical challenges remain, it represents an important direction for the future of fruit production.

Drones

Drones are becoming increasingly useful in precision horticulture because they can survey large orchard areas within a relatively short period. Depending on the type of camera installed, drones can capture RGB, multispectral or thermal images that provide different types of information about the crop.AI can analyse these images to identify differences in canopy development, plant vigour, water stress, disease symptoms and fruit distribution. For example, a drone may identify an area of an orchard showing unusual vegetation characteristics. AI can then flag that area for further field inspection by the farmer or horticulturist. This approach can save considerable time because instead of inspecting every tree in a large orchard, attention can be directed towards specific areas identified by the technology. The combination of drones, remote sensing and AI therefore provides a powerful tool for precision fruit production. It can help convert large quantities of aerial imagery into useful management information that can be acted upon at the field level.

Robotics in Fruit Production

One of the major development in smart orchards is the integration of AI with robotics. Robots can potentially assist with activities such as harvesting, pruning, fruit thinning, crop monitoring and precision weed or pest management. In such systems, AI provides the decision-making capability, while the robotic equipment performs the physical operation. For example, an AI-enabled harvesting robot can identify mature fruits and determine their exact location before attempting to pick them. Similarly, an intelligent pruning system could potentially identify branches according to predetermined canopy-management requirements. Although robotic systems still face difficulties in commercial fruit orchards, especially because fruits may be hidden behind leaves and branches, continued advances in cameras, sensors and machine learning are gradually improving their capabilities.

AI for Better Farm Decision-Making

The greatest potential of AI may not lie in any single application but in the integration of multiple technologies into one decision-making system. Imagine a mango orchard in which soil-moisture sensors continuously monitor water availability, weather stations record environmental conditions, drones periodically capture images of the canopy and cameras estimate fruit numbers. All this information can be combined with historical yield and management data.AI can analyse these different sources and provide a comprehensive picture of the orchard. It may indicate which areas require irrigation, where pest or disease monitoring should be intensified, how much yield can be expected and when harvesting is likely to begin. The farmer can access this information through a mobile phone or computer-based dashboard and use it along with field experience to make management decisions. Such integration represents an important shift from simply collecting data to converting data into actionable information. In other words, the objective is not to have more sensors or more images, but to use those data to make better horticultural decisions.

Benefits of AI in Fruit Production

Artificial Intelligence can improve fruit production by helping farmers monitor crops more efficiently and make timely management decisions. By analysing information related to soil moisture, weather, crop growth and pest or disease conditions, AI can help optimize the use of irrigation water, fertilizers and plant protection inputs, thereby reducing unnecessary resource use. It can also reduce dependence on manual labour for activities such as crop monitoring, fruit counting and certain harvesting operations. Furthermore, accurate yield and maturity predictions can assist farmers in planning labour, harvesting, transportation, storage and marketing more effectively. Another important benefit is the possibility of improving the sustainability of fruit production. When inputs are applied according to actual crop requirements rather than uniformly throughout the orchard, wastage can potentially be reduced. Targeted management can also reduce unnecessary chemical applications and improve the efficiency of water and nutrient use. In the long term, these improvements can contribute to more profitable and environmentally responsible fruit production.

Challenges in AI-Based Fruit Production

Despite its enormous potential, AI is not a solution for every problem in fruit production. One of the major challenges is the availability of large quantities of high-quality data. AI systems need to be trained using reliable images and field observations and their performance may decline when they are used under conditions that differ significantly from those in which they were developed. Fruit orchards are highly environment variable. Different cultivars, tree architectures, training systems, climates, soil types and management practices can influence the appearance and development of fruits and plants. Fruits may also be hidden behind leaves or branches, while changing sunlight conditions can affect image quality. Recent reviews of AI-based fruit quality management have identified data availability, model generalization, standardization and implementation cost as important challenges for wider adoption (El-Beltagi *et al.*, 2026**)**.Cost is another important consideration, especially for small and marginal farmers. Drones, sensors, cameras, software and robotic systems may require considerable initial investment. Farmers and field staff also need adequate technical knowledge to operate these technologies and interpret their outputs. Therefore, successful implementation of AI in horticulture will require affordable technologies, training, local technical support and systems that are designed according to the needs of farmers.

The Future of Fruit Production: From Smart Orchards to Autonomous Orchards

The future of fruit production is likely to involve increasing integration of AI with sensors, drones, remote sensing, robotics and digital farm-management systems. A future orchard may continuously monitor its own soil and environmental conditions while cameras observe crop development and AI systems analyse changes in plant health, flowering, fruit growth and maturity. In a more advanced system, AI could predict disease risk before visible symptoms become widespread, estimate crop yield weeks or months before harvest and identify fruits approaching the desired maturity. Robots could then perform selected operations such as harvesting, pruning or thinning. Farmers and horticulturists would continue to play a critical role, but their decisions would be supported by continuously updated information from the orchard. The concept is therefore moving towards the semi-autonomous or autonomous orchard, where routine monitoring and selected management activities can be automated. Recent research in intelligent fruit production is increasingly emphasizing the integration of AI with IoT, computer vision, sensors and robotics rather than treating these technologies as separate systems. Such integration is likely to be central to the development of future smart orchards. However, the ultimate goal should not simply be to make orchards technologically advanced. Technology should help make fruit production more productive, profitable, precise, sustainable and resilient.

Conclusion

Artificial Intelligence is emerging as an important technology that can reshape the future of fruit science. Its applications extend from orchard monitoring and pest and disease detection to precision irrigation, flower and fruit counting, yield prediction, fruit quality assessment and robotic harvesting. The combination of AI with drones, sensors, computer vision, remote sensing and robotics has the potential to transform conventional orchards into intelligent production systems. However, successful adoption of AI will depend on more than technological development. Reliable datasets, affordable equipment, farmer training, appropriate rural infrastructure and collaboration between horticulturists, engineers, data scientists and farmers will be essential. AI should therefore be viewed as a tool that strengthens horticultural decision-making rather than as a replacement for farmer experience and scientific knowledge.The transition from observing the orchard to predicting and intelligently managing it could become one of the most significant developments in fruit science in the coming years.