of agronomists and plant scientists to diagnose affected ginger plants and correct the labeling of datasets. Computer analysts need to work with plant pathologists using various skill sets, such as image analysis, data analysis, ML, programming, and software development. The shortage of these skill sets will pose a big challenge. To overcome this, effective collaboration between researchers and practitioners is required from different institutions and also different countries.

B. Cost Implication

The cost of data collection in terms of manpower, the cost of data acquisition systems, and the need for high-end computers for data analysis remain a major challenge. Setup cost, which involves hardware and software systems, can range from hundreds to thousands of dollars. Other cost includes deployment cost, training of farmers on the use of the AIoT systems, maintenance costs, such as hardware replacement, and Internet costs. To overcome this challenge, there is a need to use AIoT to achieve a return on investment within a reasonable time. Also, collaboration between farmers and the government can help overcome the initial cost.

C. Data Acquisition and Processing

The availability of adequate datasets that are taken from the field that encapsulate the various stages of growth of ginger and the real-life images of the diseases on the plant with different backgrounds and orientations remains a challenge. This can be time- and resource-consuming in monitoring and collection of data. The detection of leaf disease, as well as the collecting and labeling of a large number of disease photos, requires a huge amount of people, material resources, and financial resources. Some plant diseases have a shorter onset period and are more difficult to collect [9]. Furthermore, the storage and processing of datasets can be demanding. For instance, the use of high-resolution images and hyperspectral images involves the processing of a large amount of data. This poses some computational challenges. Hence, the need to employ parallel processing, batch processing, and hardware acceleration could solve these computational challenges and provide a real-time analysis as a viable solution.

D. Deployment Challenges

While ML has been extensively studied in academia, many applications remain in the laboratory stage. This is largely due to the controlled environment that laboratories provide for data collection and annotation, which is essential for training and validating reliable AI models. However, several deployment challenges must be addressed to transition ML from the lab to the field. These include the need for reliable infrastructure, such as power, connectivity, and durable hardware suitable for agricultural conditions. In addition, successful deployment requires collaboration among agricultural researchers, extension services, and farmers. The choice of deployment methods, such as smart mobile phones, IoT devices, robots, or drones, has different technical requirements. A comprehensive framework is also needed to govern data collection through online platforms, manage data collection via individual smartphones, facilitate data submission to a cloud platform, and process the collected data.

VIII. Future Work

In this section, the potential areas that can revolutionize ginger farming are discussed as follows.

A. AIoT Innovation

The application of AIoT for ginger production is expected to open up more research opportunities. More research work is expected in the use of IoT for real-time monitoring of soil moisture, pH, nutrients, and other farm-related variables in order to optimize ginger crop yield. More research work is needed to deploy IoT energy-efficient systems in ginger farms that take into consideration low-power wide area communication technology or energy harvesting systems. The adoption of AIoT will enable the prediction of weather patterns and disease outbreaks in ginger farms. The provision of real-time monitoring of farm variables using IoT and prediction using ML algorithm will enhance ginger farm management greatly [89].

B. Smartphone Applications

The use of smartphones has been explored for disease detection of soft rot in ginger [80]. However, more research work is needed in the use of smartphone-assisted early diagnosis of other ginger diseases and pest infections, as mentioned in Section III. The development of a smartphone application that can guide farmers in planting, harvesting, processing, and marketing of ginger is needed. Features, such as integrated pest management, that cover preplanting, sowing, vegetative stage, and rhizome development stage would be useful for ginger farmers. Lightweight DL models that can be deployed on smartphones for online and offline [90], [91], [92], [93] disease and pest management for ginger plants is an open research area.

C. Automation and Robots

The use of robots for planting, monitoring, and harvesting ginger, guided by IoT sensors and ML algorithms, is expected to attract more research interest. Labor-intensive activities, such as sorting good and bad ginger seedlings, sorting ginger seedlings according to sizes, and ginger shoot orientations in planting [69], [81], can be automated. More research into the use of robotics for remote plant disease diagnosis and precision plant protection for ginger using virtual reality and digital twins is expected [94]. Also, the use of drones equipped with HSI for disease detection in ginger-cultivated fields is a promising area.

D. Explainable AI (XAI)

The concept of XAI enables the AI system to provide clear understandable insights into the decision-making process [95], [96]. Recently the XAI has been extended to the field of agriculture and, in particular, to predict the probability of disease occurrence in corn cultivation [97], [98]. XAI tools, such as