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Thriving Accelerators for Smart Agriculture in Taiwan during COVID-19 Pandemic

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ABSTRACT

During the COVID-19 pandemic and post-pandemic era, the behaviors and patterns of agricultural production have changed enormously. Labor shortages and supply chain disruption caused trouble to agricultural operations. Furthermore, how the tasks of smart agriculture affected by the COVID-19 pandemic is of concern. For example, the fragility of food supply chain has increased, thus leading each country to re-emphasize food security and strive to increase domestic food production. In order to solve labor shortages, more automation technologies will be introduced into the production system. The business model of "remote behavior" and "home economy" has emerged. Also, the traditional offline businesses will gradually be replaced by novel online ones. Consumers began to pay attention to local and healthy foods, and were expecting more on food safety and traceability. Each country continues to promote policies on increasing the adoption of smart technology in the agricultural industry. According to the trends and issues of post-pandemic era, smart technologies might be appropriate solutions for transforming agricultural industry. Agriculture in Taiwan is small-scale farming, especially traditional labor-based farming. If production management and trade of produce can be supplemented by low-cost and labor-saving machinery, auxiliary equipment and sensing components, together with the introduction of advanced technologies such as ICT, IoT, Big Data, and Block Chain, the goals of reducing the burden of farming and labor demand, providing farmers with a more efficient farming management model, and alleviating the impact of the COVID-19 pandemic could be realized. Hence, the Taiwan Agricultural Research Institute (TARI) committed to create advanced technologies and solutions to assist agricultural transformation. Now experts in smart agriculture have already had some preliminary results. Smart technologies for remote monitoring and introduction of automation and robots can solve labor shortage, such as disinfection drones and automatic grass pushing and delivering robot. The adoption of innovative digital technology for remote consultation and diagnosis can reduce the risk of COVID-19 transmission. Using artificial intelligence to develop agricultural digital twins is helpful for developing smarter post-pandemic agriculture. The protected agriculture technology for urban agriculture and greenhouse vertical farming can increase food supply. New food traceability systems using smart technology, such as "Agricultural Food Calendar" system and "i-PLANT" agricultural farm management system can strengthen food safety control and improve consumer confidence. In summary, the pandemic is undoubtedly an unexpected catalyst for accelerating the intellectualization and digitalization of agriculture. In the years to come, there will be a vision for experts of all fields to work together to turn the crisis into a turning point for upgrading agriculture.

Keywords: COVID-19 pandemic, post-pandemic era, smart agriculture, smart technology, labor shortage, food security

INTRODUCTION

Since the outbreak of Coronavirus disease (COVID-19) in December 2019, the economic activities of people around the world, including agricultural production and consumption behaviors and patterns have completely changed. The food supply chain has been hit hardest by COVID-19, which not only caused food security of most vulnerable segment of population at risk (Poudel *et al*., 2020), but also limited the availability of labor for harvesting, processing, transport, and distribution (Henry, 2020). More than 60% of the world's population relies on agriculture for survival. Due to high transmission risk of COVID-19, farmers' health and labor shortages have become major issues in agricultural production (Poudel *et al.*, 2020). In the face of labor shortages, this is a good timing to introduce automation and digitization in the agricultural production phase (Henry, 2020). This could result in more investments in automation of harvesting and processing, minimizing manual steps in the whole production chain. In addition, smart farming technology and big data can help farmers overcome dependency on farm labor and make better decisions (Lioutas and Charatsari, 2021).This article aims to summarize some of the main impacts that the pandemic is having on agriculture, analyze the development of smart agriculture, and explore the opportunities for further development of smart agriculture during the pandemic, especially focuses on how smart technologies in Taiwan could assist in the transformation of agriculture industry during the pandemic.

TRENDS AND ISSUES ON GLOBAL AGRICULTURAL DEVELOPMENT DURING AND/OR AFTER THE COVID-19 PANDEMIC

The impact of the COVID-19 pandemic on agriculture has not only worsened the existing labor shortage issue, but also caused tremendous changes in the production processes, trade systems, and consumer behaviors. During the pandemic, Krishnan (2021) identified the areas of innovation critical to building a healthier and more sustainable food system, and those areas that would be most impacted by the pandemic. Krishnan's team delved deep into pandemic economic history and focused on the structural and cyclical undercurrents sculpting the post-pandemic worlds. Five technological areas they explored include Decommodification of Protein, Channel Digitization, Food & Agriculture Digitization, Controlled Environment Agriculture, and the Convergence of Food and Health. Krishnan concluded that perhaps accelerated by COVID-19, the potential common thread that could bridge us to the future is technology. There is a need to continually see the pandemic act as a catalyzing agent to accelerate trends that were in motion before it began. Apparently, food and agriculture have undergone significant structural changes that will alter the course of the industry. The application of common information platform for consumer-friendly food production to foster data-driven agriculture in Taiwan was described by Lu *et al*., (2019) and Tsay *et al*., (2019), which also depicted the status of smart agriculture in Taiwan in the pre pandemic era. After the effort of promoting smart agriculture in Taiwan for more than four years, people have grown from the unclear concept of smart agriculture to using it as a buzzword. Fortunately, the inputs of smart agriculture R&D have increased farmers' awareness and consideration to adopt new technologies, such as cloud technology, Big Data, Internet of Things (IoT), geographic information systems (GIS), smart machines, sensors, etc. Through the adoption of these technologies, farmers can remotely monitor and engage themselves in agricultural production activities to relieve the negative impact caused by the COVID-19 pandemic, which brought positive effects on the digital agricultural market due to labor shortage and supply chain disruption. In the post-COVID-19 era, the global digital agricultural market is estimated to increase from US$5.6 billion in 2020 to US$6.2 billion in 2021, with the compound annual growth rate of 9.9%, due to increased demand for agricultural products and higher requirements for food safety and quality. It is expected that government policies supporting the need for the digitization of agricultural processes and the effective use of natural resources, as well as reduced supply of migrant labors, could increase the adoption of digital agricultural technology (Markets and Markets™, 2020). According to Villars *et al*., (2020), as spurred by the world reaction to the disruptions caused by the global pandemic in 2020, the global economy remains on its way to its "digital destiny." Most products and services are based on a digital delivery model or require digital augmentation to remain competitive. The majority, 65%, of global GDP will be digitalized by 2022, driving US$6.8 trillion of IT spending from 2020 to 2023. The COVID-19 pandemic highlighted the ability to rapidly adapt and respond to unplanned/unforeseen business disruptions that will be a clearer gauge of success in increasingly digitalized economy. A large percentage of a future enterprise's revenue depends upon the responsiveness, scalability, and resiliency of its infrastructure, applications, and data resources. However, factors such as the lack of background knowledge in science and technology and the high investment cost in smart equipment in agriculture hinder the expansion of the smart agriculture

market. If low-cost automation or smart equipment is available in small-scale farming, especially traditional labor-based farming, it is expected to create higher opportunities for growth (Origius Systems Private Limited company, 2020).

In addition, the risk of misusing collected data will lead to anti-competitive practices (including price discrimination and speculation in the commodity market). It is noteworthy that the information related to yields and performance contained in this data can hold incredible value and could provide a market advantage to seed and fertilizer companies (Foote, 2020). The widely discussed "new normal" in the post-pandemic era refers to the development of a "zero-touch economy" under the policy of reducing contacts and maintaining social distance. The business model of "remote behavior" and "home economy" also emerged.

The "new normal" in the agro-industry are as follows:

In the production system, the trade protectionism continues to rise as well as the recognition that the fragility of the food supply chain has increased, have led each country to re-emphasize food security and strive to increase domestic food production.

With regard to farmer's economy, when farming patterns change, more automation technologies may be introduced on the production side, and the boundary of each specialized division will become clearer, but it is also possible that technology and capital-intensive large-scale agricultural enterprises may replace small-scale farmers (Shi, 2020).

With transformed trading system, companies begin to diversify supply chains. The COVID-19 pandemic exposed the fragility of the global supply chain, rendering companies to switch to regional or localized business management models, and to develop more channels to reduce reliance on suppliers from foreign countries to mitigate risks (Bulgari *et al*., 2021). Basically, if possible, diversifying the procurement of products or inputs from a large number of factories and regions makes them less susceptible to factory shutdowns. Systems were implemented so that customers can order online and pick up the goods in local stores or via home delivery. The future supply chain will not only consider cost and efficiency as the main factors, but will instead focus more on the ability to adapt to risk dispersion and supply safety to cope with future disruptions. For example, the companies may keep a little more stocks to deal with significant fluctuations in demand, rather than paying too much attention to the just-in-time supply system (Lusk and Boehlje, 2020).

In terms of transformation in retail business, companies rethink their strategies on virtual and real integration. Traditional distribution will be weakened. Offline (physical stores) will gradually be replaced by online business model. However, the "digital gap" will be a new way of market competition.

On the consumer side, changes in food consumption behavior, such as online purchases and food distribution, may become permanent (Lusk and Boehlje, 2020). Consumers begin to emphasize and value domestic and healthy foods, and expect more on food safety and traceability. In addition, because of quarantine policy, consumers have re-connected with botany and horticulture, which indirectly made relevant companies the beneficiaries of the pandemic (Fitch Solutions, 2020; Bulgari *et al*., 2021).

Regarding the actions of the government, in response to the pandemic, each country continues to promote policies on smart farming, effective use of natural resources, and reduce the demand for migrant workers as well as increase the adoption of smart technology in the agricultural industry. For example, in the EU's draft recovery plan, promotion of smart agriculture will be a key strategy in the post-pandemic era. EU agri-food department proposed to launch a 3.5 billion euro investment in developing smart agriculture in the next two years. Fast and reliable network allows farmers to obtain better consulting services and online courses, and assists them to build a more efficient and profitable farming model (Foote, 2020). The Ministry of Agriculture, Forestry and Fisheries of Japan, based on the "Basic Plan for Food, Agriculture and Rural Areas," formulated the "2020 Agricultural Innovation Research Strategy," in which smart agriculture, eco-friendly farming, and bio-economy are clearly defined as targets of agricultural R&D for interdisciplinary cooperation (Agricultural Science and Technology Decision Making Information Platform, 2020).

In response to post-pandemic changes in demand and distribution channels, Peng (2020a) pointed out the integration of processing, transportation, and preservation of agricultural products, and more efforts to identify needs and changes of the markets are needed in order to seize business opportunity. Scholars also suggested that farmers could collect and analyze market demand data to design their own production lines and products to seize new business opportunities. For example, because of the pandemic, consumers stopped eating out and started to buy ingredients and cook at home. In the past, agricultural products and ingredients were mostly purchased in traditional markets, but now e-commerce stores and supermarket are more popular for packaged ingredients to avoid unnecessary personal contact.

DURING THE PANDEMIC, HOW CAN SMART TECHNOLOGY ASSIST IN THE TRANSFORMATION OF

THE AGRICULTURE INDUSTRY?

Traditional agriculture is normally labor-intensive, except in developed countries. Under labor shortages and interruption of the food production supply chain during the pandemic, agricultural productivity is expected to be severely affected. Fitch Solutions (2020) predicts that it may accelerate the mechanization in developing countries and the adoption of new agricultural technologies, such as indoor farming, vertical farming and hydroponic cultivation. Agriculture in Taiwan is dominated by small-scale farmers. If production management and trade can be supplemented by low-cost and labor-saving machinery, auxiliary equipment and sensing components, together with the introduction of advanced technology such as ICTs, Internet of Things (IoT), Big Data, and Block Chain, it is believed to reduce the burden of farming and labor demand, provide farmers with a more efficient farm management model, and alleviate the impact of similar pandemics.

In the post-pandemic era, the focus is on the infrastructure construction of fresh food (mainly agricultural facility, flexible agricultural supply chains, and new types of e-commerce services) and the innovative technologies that lead the wave of innovation. Solutions and current technologies of smart technology for transforming agro-industry are described as follows.

Smart technology for remote monitoring and introduction of automation and robots can solve labor shortage under the quarantine policy

Taiwan Agricultural Research Institute (TARI) applies unmanned drone technology to pineapple orchards, in order to reduce manpower and time for patrolling the fields and eliminate safety hazards caused by sharp edges of pineapple leaves. Large-areas and high-resolution images can also be captured in a short time, and combined with Edge Computing technology to simultaneously inform farmers of nitrogen content, health conditions, and blooming status of each pineapple in the field. Through human-machine collaboration, the efficiency of investigation and management will be improved, and fertilizers and flower stimulating agents can be utilized more precisely (Zhang, 2020). In addition, drones can also be used for pesticide spraying. Take dragon fruit as an example, the spraying volume of drones is reduced to only 1/10 to 1/15 of the manual spraying, and the spraying efficiency can be increased by 4 times, which greatly contributes to eco-friendly farming. In the future, drones will integrate monitoring and spraying functions enabling them to automatically identify symptoms of diseases for spraying. For issues such as labor shortage, eco-friendly farming and food safety, smart pesticide spraying drones are considered to be the best solution.

Figure 1 shows the digital application used by TARI for remote monitoring of farms or greenhouses. By integrating IoT with modules of data analysis, expert suggestions and abnormal analysis on the Common Information Platform (CIP), it provides sensing data, weather information, operation suggestions and malfunction warning and is accessible through personal computers, tablets and mobile phones to manage farming or greenhouse facilities.

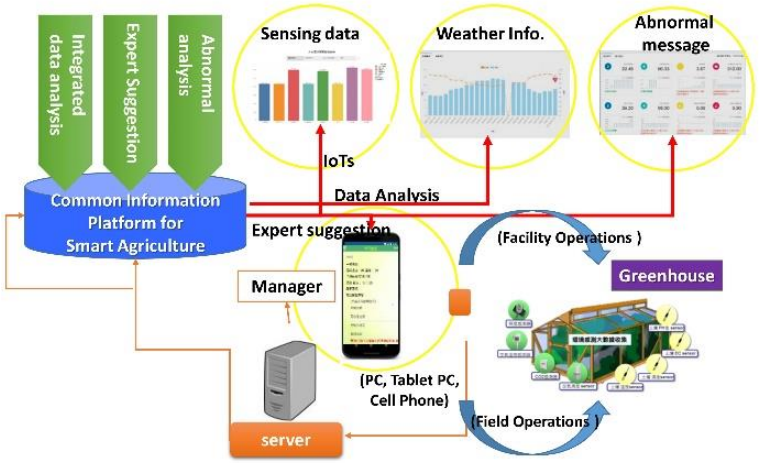

Figure 1. Digital application used to enhance remote monitoring of farms or greenhouses.
Source: Smart Agriculture website, 2019-2020.

For rice production, farmers can use the "Brown Planthopper Smart Monitoring and Warning System" developed by TARI, deploying the Internet and image recognition technology to link to a remote database to easily monitor the density of the brown planthopper in the field for decision making. Agricultural experts can also use this system to gather information on the density of brown planthopper in various regions, analyze the distribution of the brown planthopper, and access timely information to agricultural institutes for warnings and prevention.

In the mushroom industry, TARI introduced automation and smart monitoring for cultivation, which doubles the output and can cultivate 9,000 packs per hour, about 15 times more efficient than manual cultivation. The automation of mushroom grow bag system allows the daily production capacity up to 60,000 bags, which greatly reduces manpower and improves efficiency. In addition, TARI adopts the principle of automated storage system logistics to develop an automated mushroom packaging, storage and loading/unloading system. This system can save about 90% of the labor input compared with the traditional manual production, and improve productivity by more than 5 times.

In the livestock industry, a cattle farm in Changhua County of Taiwan introduced an automatic grass pushing and delivering robot. The robot is equipped with an image inspection function, which can be remotely controlled with a mobile phone, and the status of the cattle can be checked at any time through the image. It is the world's first feed pushing and delivering robot with eye and ear unit. The robot increases cows feeding frequency, the dry feed intake by 6-10%, and the milk yield by 3-8%. At the same time, labor demand of 3-4 hours per day is no longer needed. The farm also introduced calf feeding robots to assist in feeding calves, which reduced manpower and increased the survival rate of calves to 95% (Smart Agriculture website, 2019-2020).

The adoption of innovative digital technology for remote consultation and diagnosis can reduce the risk of COVID-19 transmission

The smart agricultural pest chat robot developed by TARI can analyze biting marks or symptoms and provide answers on possible types of pests with pictures and text. In addition, the Line chat robot "Pest Consultation Assistant" performs semantic analysis. When keywords are found in the dialogue, it will search for relevant pest information in the platform and share it instantly with the demand side, which enables timely professional assistance for pest management in the field.

Different from the general video application, the Taiwan Livestock Research Institute developed a remote interactive video system for the dairy industry, which provides maintenance guidance for dairy farm machinery and equipment, and record key maintenance techniques in a digital file for database. Experts of cattle care (such as dystocia, pre-diagnosis, etc.) interact remotely to provide immediate assistance for livestock owners. It is a powerful tool during pandemic (Smart Agriculture Website).

Using artificial intelligence to develop agricultural digital twins can develop smarter post-pandemic agriculture

COVID-19 accelerates the adoption of AI-driven technologies, and artificial intelligence is helping to create a post-pandemic agricultural world that is more efficient, less wasteful, and smarter than before. Autogrow Company uses the FarmRoad platform to crack the code, which enables the tomato yield prediction model to reach 90% accuracy within six weeks (Farmroad, 2020). This model combines the biophysical understanding of crop varieties, crops and environmental data, and AI-based model and engine which are built and hosted on the AWS cloud and can be delivered to any agri-enterprise in the world.

In addition, TARI together with the Institute for Information Industry jointly established an information platform to integrate data of IoT. With Sinon Corporation’s vegetable greenhouse as a model and in collaboration with Guoxing Information Company, both human intelligence (HI) and artificial intelligence (AI) technologies were incorporated to build digital twins of greenhouse experts (Figure 2) that offer diagnosis on operating habits of worker and provide management suggestions. Smart analysis of controlled environmental factors may lower the technological threshold for new farmers without experience on environment control to enter the industry. In addition, it also allows managers to focus on production management and expand operations, reduce the pressure and time of greenhouse management, and decrease labor expenditure of farm management (Wang and Lu, 2020). In particular, the digital twin model promotes the digitized professional or expert skills, through which it can be passed on to novices or the next generations with a flat learning curve.

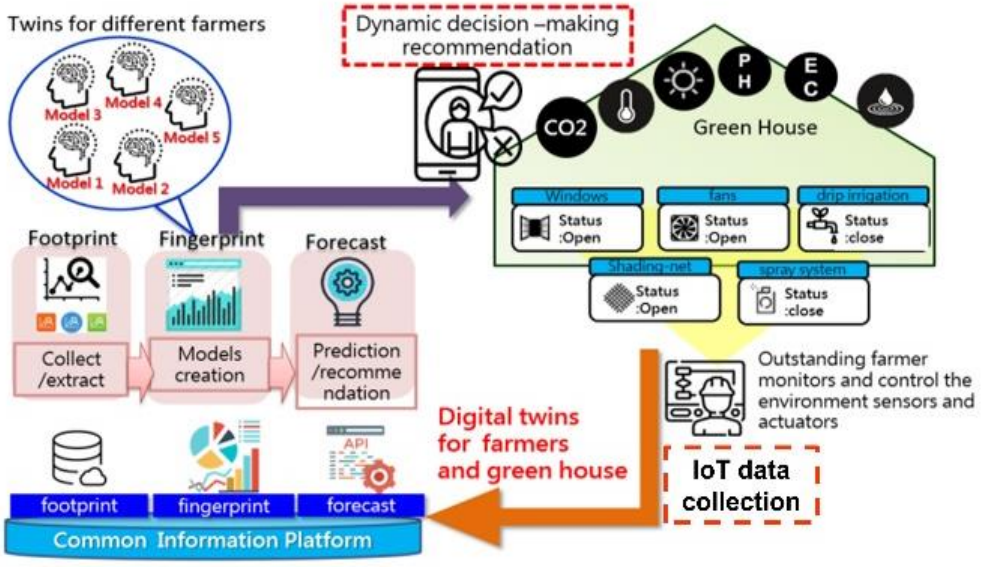

Figure 2. The digital twin of greenhouse experts.
Image source: Smart Agriculture website, 2019-2020.

Using the protected agriculture technology for urban agriculture and greenhouse vertical farming can increase food supply

Due to the pandemic, agricultural production systems such as facility agriculture, vertical farms, and urban farms, with IoT connected to information platforms, have gradually been transformed into a feature of new agriculture, and have partially solved the problem of food supply and food supply chain disconnection. In particular, several characteristics of vertical farms are important and urgent during the pandemic (Cuello, 2020a), such as local production to provide transparency and trust in agricultural products; automated farming to reduce labor shortages caused by pandemic; controllable facility cleaning and operation to significantly reduce infection risk of workers; modular transportation containers to easily transport to areas with strict quarantine rules; reliability and consistency of high-yield and high-quality agricultural products throughout the year that are not affected by seasons and weather conditions, etc. Pulighe and Lupia (2020) proposed the opinion that urban agriculture in developed countries should be fostered with emerging growing practices and edible green infrastructures, such as vertical farming, hydroponics, aeroponic, aquaponic, and rooftop greenhouses.

Newtalk News (2020) pointed out that the Singaporean government announced that it would invest NT$630 million to achieve a food self-sufficiency rate of 30% in 2030. One of the projects to promote production is to invest in urban agriculture and to develop "rooftop farms" starting in May 2020. Allan Lim, the co-founder of "Comcrop" company establishing the first rooftop commercial farm in Singapore, believes that this plan will help accelerate the expansion of production capability and expects to build 7 more greenhouses on roof farms of approximately 80,000 square feet, thereby increasing production capacity 10 times in 6 to 8 months.

Using smart technology to establish a new food traceability system can strengthen food safety control and improve consumer confidence

The pandemic has shifted the consumption pattern from physical purchase to online business models, and highlighted food safety of agricultural products. Establishing a well-rounded traceability system may be the best solution which could enable consumers to consume agricultural products at ease, and could allow producers to effectively monitor and manage the distribution of agricultural products. In addition, the traceability system also allows users to feel the sense of presence, or increase participation in different fields, greatly increasing user acceptance and creating new value for the agricultural products.

Through the CIP in Smart Agriculture, TARI established the "Food Supply Flow Audit and Inquiry System," which is a combined data of traceable agricultural products of the Council of Agriculture and the school lunch program of the Ministry of Education, to integrate the food supply chain and food safety notification system. The system prevents food safety incidents, and acts as a checkpoint system for school lunch management, thereby retrieving timely food safety information and providing safe and hygienic school meals. The system connects links of the entire food chain for stakeholders to acquire and apply

the data. It is one of the industrial examples from smart production to food safety traceability.

In addition, the "Agricultural Food Calendar" launched by the Council of Agriculture shows consumers the whole process of agricultural food products through QR Code, including production, processing, packaging, and trading. The agricultural farm management system "i -PLANT", developed by TARI, and is applied to record production, along with GIS assisted by IoT and aerial photography technology. The agricultural farm management system not only enables smart farming, but also records growing period and overlays information layers with environmental big data, allowing farmers or agricultural enterprises to conduct production risk management and decision analysis to ensure the safety and quality of agricultural food. The Agricultural Food Calendar has the spirit of food and agriculture education, while “i-PLANT” records agriculture operations. These two technologies complement each other and are the ideal tools for smart farming management and traceability.

Shortening the food supply chain and innovating agricultural and food services can strengthen local supply and reduce energy consumption

The COVID-19 pandemic affects the fresh food supply chain severely. Many countries have shown the vulnerabilities of supply chains and are seeking solutions. Scholars suggest that the fresh food supply chains should be re-planned to strengthen its resilience, inclusiveness and sustainability. Several key points must be considered, including the importance of locality, inclusion of small and medium-sized producers, integration of food services and retailers, inclusion of greenhouse or vertical farm producers, linking farms with renewable energy, and providing supply chain certification, *etc.* (Cuello, 2020b). In order to avoid close contact and emphasize social distance, services or disruptive business models in the fresh food supply chain have emerged, such as online retail stores or new food supply models (Valoral Advisors, 2020; Van den Boezem and Burwood-Taylor, 2017). As suggested by Lioutas and Charatsari, a new winning strategy could promote the diversity of agri-food production and encourage the reconnection of farmers and consumers through community marketing schemes. It can facilitate the distribution of products during periods of crisis, and the mainstream distribution channels could coexist in food supply chain. For example, because of the lockdown or avoiding the infection risk, many people turn to Community Supported Agriculture (CSA) that provides "Farm-To-Door" service. The CSA model supports small farmers in local community. In addition to shortening food mileages and reducing greenhouse gas emissions, CSA farmers tend to farm in an environmentally friendly way, therefore local consumers can buy safe and fresh food of the season (Wang, 2020). Although the COVID-19 pandemic in Taiwan is less severe compared to the rest of the world, there are also businessmen who seize the opportunity to cooperate with the government and take early preventive measures. For example, Yunlin Agricultural Products Logistics Company decides to officially expand into " LR Taipei Cold Hub (物流共和國台北冷鏈園區)" in September next year, and jointly create the "Yunlin Food Ingredients Supply Chain Support Group", with the purpose that Yunlin's high-quality ingredients can be delivered to consumers in the shortest time and freshest state, and thus it will become a base for Taiwan's agricultural exports (Peng, 2020b).

CONCLUSION

The outbreak of COVID-19 pandemic in 2020 has caused turmoil around the world and may change the geopolitical and socio-economic norms, prompting countries to implement stimulus plans. The COVID-19 pandemic will amplify and accelerate general trends in agricultural sectors, bringing challenges to agricultural development, but it also brings many potential opportunities. The COVID-19 pandemic reveals the importance of food and how stakeholders are working to ensure fresh food being provided to consumers, which raised awareness of agriculture and future investment. Morris Chang, founder of Taiwan Semiconductor Manufacturing Company (TSMC), once said “After the pandemic, the way of life will be changed.” And changes will create new demands and opportunities, which is also true in agriculture. The pandemic is undoubtedly the best catalyst for accelerating the intellectualization and digitalization of agriculture. In the years to come, it will be a goal for experts of all fields to work together to turn the crisis into a turning point for upgrading agriculture. Taiwan’s agriculture is based on a solid foundation of agricultural R&D and application. It is believed that through interdisciplinary collaboration and the use of advanced technologies, such as sensing technology, smart machine, IoT, and Big Data analysis, it will successfully transform agriculture and break new ground in the post-pandemic era.

REFERENCES

Agricultural Science & Technology Decision-making Information Platform. 2020. Integrated strategies

to promote smart agriculture, friendly environment and biotechnology in Japan. Technology meeting for agriculture, forestry and fishery. https://agritech-foresight.atri.org.tw/article/contents/3262.

Bulgari , R., A. Petrini, G. Cocetta, C. Nicoletto, A. Ertani, P. Sambo, A. Ferrante and S. Nicola. 2021. The impact of COVID-19 on horticulture: critical issues and opportunities derived from an unexpected occurrence. Horticulture 7, 124. https://doi.org/10.3390/horticulturae7060124.Chang, Chih-Yuan. 2020. Intelligent technology facilitates the production and marketing of pineapple industry. Agriculture World Magazine. 448, 59-61.

Cuello, J. L. 2020a. Coronavirus pandemic highlights vital need for vertical farms having the following salient features in world cities. https://vertical- farming.net/blog/2020/03/25/coronavirus-vertical-farms/.

Cuello, J. L. 2020b. Re-engineering America's fresh-produce supply chain post COVID-19 for greater resilience, inclusiveness and sustainability. https://vertical- farming.net/blog/2020/04/27/re-engineering-americas-fresh-produce-supply-chain-post-covid-19-for-greater-resilience-inclusiveness-and-sustainability/.

Farmroad. 2020. Autogrow cracks the code with FarmRoad– "90 percent accuracy for new tomato yield prediction code." https://www.hortidaily.com/article/9218422/90-percent-accuracy-for-new-tomato-yield-prediction-code/.

Foote, N. 2020. COVID-19 Crisis could 'Kick off digital revolution in agriculture.' EURACTIV.com. https://www.euractiv.com/section/agriculture-food/news/covid-19-crisis-could-kick-off-digital-revolution-in-agriculture/.

Fitch Solutions. 2020. Four global agribusiness trends to watch post COVID-19. https://www.fitchsolutions.com/corporates/commodities/four-global-agribusiness-trends-watch-post-covid-19-21-04-2020.

Henry, R. 2020. Innovations in agriculture and food supply in response to the COVID-19 pandemic. Mol. Plant. 13(8):1095-1097. doi:10.1016/j.molp.2020.07.011

Krishnan, S. 2021. The Ingredients for a Food System Revolution: What Past Pandemics Teach Us About the Future of Food and Agriculture. S2G Ventures.

Lioutas, E. D. and C. Charatsari. 2021. Enhancing the ability of agriculture to cope with major crises or disasters: What the experience of COVID-19 teaches us. Agriculture Systems 187(103023).

Lu, C. T., T. S. Liu, C. K. Yang, and J. R. Tsay. 2019. Application of common information platform and agricultural management system "i-PLANT" for consumer-friendly food production in Taiwan. J. Taiwan Agric. Res. 68(4):261–273.

Lusk, J. L. and M. D. Boehlje. 2020. For farmers and consumers, a crazy year in food. THE WALL STREET JOURNAL. https://www.wsj.com/articles/for-farmers-and-consumers-a-crazy-year-in-food-11608071329

Markets and Markets™. 2020. COVID-19 impact on digital agriculture market. AGI 7680. https://www.marketsandmarkets.com/Market-Reports/covid-19-impact-on-digital-agriculture-market-222616344.html.

Newtalk News. 2020. Epidemic assists? The accelerated development of urban agriculture and vertical farms has solved the global supply chain crisis. https://newtalk.tw/news/view/2020-05-01/399665.

Origius Systems Private Limited Company. 2020. Artificial intelligence in agriculture market have impacted positively due to the COVID-19 pandemic. https://www.pharmiweb.com/press-release/2020-11-05/trend-artificial-intelligence-in-agriculture-market-have-impacted-positively-due-to-the-covid-19-pa.

Peng, Hsuan-Ya. 2020a. Agriculture will take the lead after the epidemic, some scholars emphasized we need to analyze the market trend, innovate and transform accordingly. United Daily News. https://udn.com/news/story/7266/4532200.

Peng, Hsuan-Ya. 2020b. Seizing the business opportunities up to tens of billions of cold chain! Yunlin Agricultural Products Logistics Company decides to create the "Yunlin Food Ingredients Supply Chain Support Group". United Daily News. https://udn.com/news/story/7266/4900055.

Poudel, P. B., M. R. Poudel, A. Gautam, S. Phuyal, C. K. Tiwari, N. Bashyal, and S. Bashyal. 2020. COVID-19 and its global impact on food and agriculture. J. Biol. Today's World. 9(5): 221-224.

Pulighe, G. and F. Lupia. 2020. Food First: COVID-19 outbreak and cities lockdown a booster for a wider vision on urban agriculture. Sustainability 12, 5012; doi:10.3390/su12125012.

Shi, Bo-Rung. 2020. Will food protectionism emerge? In the post-epidemic era, the economic security of farmers should be considered. Environment information center. https://e-info.org.tw/node/224284.

Smart Agriculture website. 2019-2020. Promotion status and practical examples of Smart Agriculture

Project. https://www.intelligentagri.com.tw/xmdoc?xsmsid=0J142605106593363792.
Tsay, J. R., C. T. Lu, and T. C. Tu. 2019. Application of common information platform to foster data-driven agriculture in Taiwan. International Symposium on Developing Innovation Strategies in the Era of Data-driven Agriculture, October 29-30, 2019 in Jeonju, Republic of Korea. (https://ap.fftc.org.tw/article/1632, visit on 8/11/2020)
Valoral Advisors. 2020. Mapping the global opportunities in the food and agriculture investment space post COVID-19. https://www.valoral.com/wp-content/uploads/Valoral-Advisors-Food-And-Agriculture-Investments-Post-COVID-19.pdf .
Van den Boezem and Burwood-Taylor. 2017. The state of agrifood tech startups in Europe. (Food Delivery). https://siliconcanals.com/news/startups/dutch-modern-milkman-picnic-raises-staggering-e100m-countrys-wealthiest-families/.
Villars, R., H. Muscolino, W. Kurtzman, S. Findling, R. Jyoti, D. Vesset, M. Morales, J. Cooke, D. Mohan, J. Lang, A. Gillen, M. N. Rizza, C. MacGillivray, A. Nadkarni. 2020. IDC FutureScape: Worldwide IT Industry 2021 Predictions. IDC FutureScape. #US46942020.
Wang, Nai-Hui. 2020. Food supply chains is expected to reshuffle by COVID-19 impacts. Delta Electronics Foundation. https://www.delta- foundation.org.tw/blogdetail/3066.
Wang, Yi-Han and Chun-Tang Lu. 2020. By using smart greenhouse master digital twin model, a rookie farmer quickly becomes an expert. Agriculture World Magazine. 447, 76-77.

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