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Agriculture 4.0: The Promises for Sustainable Agricultural and Food Systems

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Abstract

The transformative power of industry 4.0 in agricultural and food systems (Agri-food) can be attested from the explosive disruption of agricultural production infrastructures such as connected farms, new farm equipment, and connected tractors and machines which is well-known today as Agriculture 4.0 or Agri-food 4.0. The driving force behind the emergence of Agriculture 4.0 is the dire need to increase efficiency, productivity and quality in agri-food systems, and environmental protection. This has gained attention of many researchers in the recent past and thus, making Agriculture 4.0 a buzzword among the academic literature today. Despite the fact that a number of studies have covered the applications of several disruptive technologies in agri-food, the key technologies that are transforming the agri-food have been ill-defined. Therefore, the present paper aimed at identifying the key disruptive technologies and highlighting their application areas in agri-food. Massive exploratory literature search was conducted on the published papers obtained from the electronic databases including Scopus, ScienceDirect, Wiley, Emerald insight, Taylor & Francis, and Springer. The applications of 11 disruptive technologies in agri-food were analyzed based on 119 published papers. The results showed that 5 key disruptive technologies including Internet of things, Drones, Blockchain, Big Data, and Robotics are emblematic of Agriculture 4.0 epoch. The application areas of these technologies in agri-food are clearly highlighted. The present study revealed the need for extensive research to expand the application areas of the disruptive technologies in agri-food.

Key words: Internet of things, Drones, Big Data, Blockchain, Robotics, Industry 4.0, Agriculture 4.0, Disruptive technologies, Agri-food 4.0

1. Introduction

The transformative power of industry 4.0 in agricultural and food systems (agri-food) can be attested from disruption of production infrastructures such as connected farms, new farm equipment, new implements, and connected tractors and machines (Fielke, Taylor, & Jakku, 2020; Klerkx, 2020). The driving force behind this is the need to increase efficiency, productivity and quality in agri-food systems and environmental protection (Bonneau, Copigneaux, Probst, & Pedersen, 2017; Rose, Wheeler, Winter, Lobley, & Chivers, 2021; Trendov, Varas, & Zeng, 2019). That is, the sustainability of agricultural and food systems which is pivotal for the survival and wellbeing of humans worldwide (Fraser & Campbell, 2019; Talukder, Blay-palmer, Gary, & Hipel, 2020). In fact, agriculture plays a major role in providing humans with food security and sustainability (Anshari, Almunawar, Masri, & Hamdan, 2019). Therefore, to meet this ever-increasing food demand in the era of industry 4.0, the new concept “Agriculture 4.0” was coined (Braun, Colangelo, & Steckel, 2018).

Agriculture 4.0 or the fourth agricultural revolution is the agriculture that integrates a series of innovations in order to produce agri-food products. These innovations involve extensive utilization of precision farming combined with disruptive technologies such as Internet of Things (IoT), big data, blockchain, etc. in order to achieve greater production efficiency (Valle & Kienzle, 2020). These technologies underpin concepts such as vertical farming, digital agriculture, bioeconomy, circular agriculture, and aquaponics (Klerkx & Rose, 2020). The Agriculture 4.0 is currently seen as a possible solution for improving agricultural growth, ensuring the future needs of the global population in a fair, resilient and sustainable way (Araújo, Peres, Barata, Lidon, & Ramalho, 2021). Therefore, investment in technological research is imperative to stimulate the development of sustainable solutions for the agricultural sector (Araújo et al., 2021; Bongomin, Nganyi, Abswaidi, Hitiyise, & Tumusiime, 2020).

Agreeably, Agriculture 4.0 presents both challenges and opportunities such as leapfrogging from manual and animal-driven technologies to automated and mechanized equipment in developing countries and closing the digital divide. Traditionally, agricultural mechanization is characterized by the use of tractors and engine power. In Agriculture 4.0 epoch, agricultural mechanization will be matched and even surpassed by automation and the use of disruptive technologies (Valle & Kienzle, 2020). Moreover, the development of Agriculture 4.0 or digitalization of agricultural mechanization technologies will create new opportunities that can attract youth and entrepreneurs into the sector, tackling some of the causes for rural–urban migration and contributing to the economic component of sustainability (Valle & Kienzle, 2020).

Unlocking the potential applications of disruptive technologies in agri-food has been of interest to a number of academic researchers in recent years. Hence, several technologies have been cited to be suitably applied in agri-food. However, the key disruptive technologies shaping Agriculture 4.0 era have been ill-defined among the academic and industry researchers. Thus, the outstanding contributions of this paper are twofold: identifying the key disruptive technologies and highlighting their application areas in agri-food systems.

2. Methodology

A comprehensive electronic literature search was conducted in the databases: Google Scholar, Science Direct, Scopus, Sage, Taylor & Francis, and Emerald Insight from May 2020 to May 2021 following procedures employed by Bongomin et al. (2020). The search was performed independently in all the databases and then combined with “or” and “and” operators. The

multidisciplinary databases included original research articles published in peer-reviewed journals, books, thesis, dissertations, patents, and reports covering concepts on Agriculture 4.0 between year 2015 and 2021. Thus, articles in the returned results were assessed concerning their inclusion in this study, and further searches were carried out at the Google search engine using more general search terms to broaden the search, as follows: words such as “3D printing and Agriculture,” “Artificial intelligence and Agriculture,” “Augmented reality and Agriculture,” “Big data and Agri- culture,” “Blockchain and Agriculture,” “Cloud computing and Agriculture,” “Drones and Agriculture,” “Internet of things and Agriculture,” “Nanotechnology and Agriculture,” “Robotics and Agriculture,” “Simulation and Agriculture,” “Synthetic biology and Agriculture.”

3. Definition of Agriculture 4.0

Agriculture 4.0 emerged when telematics and data management in ICT policy were combined to the already known concept of precision agriculture (Saiz-rubio, 2020). Agriculture 4.0 is known with several names including data-driven and automated agriculture (Charania & Li, 2019; Saiz-rubio, 2020), intelligence agriculture (Huang & Zhang, 2017), smart agriculture (Bu & Wang, 2019), digital agriculture (Garcia & Jerez, 2019), digital farming (Klerkx, Jakku, & Labarthe, 2019), smart farming (Skobelev et al., 2019), and farming 4.0 (Roland Berger, 2019).

Agriculture 4.0 is defined as farming in the era of industry 4.0 through digitalization (Kovács & Hust, 2018). It is also referred to as the future of farming technology which is based on the emergence of smart technology including smart devices (sensors, actuators) and communication technology (Clercq, Vats, & Biel, 2018; Kovács & Hust, 2018). Simply put, Agriculture 4.0 is the fourth evolution in the farming technology which is unprecedented and has similar trends to Industry 4.0 as presented in Table 1 (Klerkx & Rose, 2020; Saiz-rubio, 2020; Zambon, Cecchini, Egidi, Saporito, & Colantoni, 2019; Zhai, Martínez, Beltran, & Martínez, 2020).

Table 1. Transition in Industrial revolution and Agriculture

Transition	Industrial revolution	Agricultural revolution
Level 1	First industrial revolution (Industry 1.0) Mechanical production, rail road, steam power	Agriculture 1.0 Labor-intensive, Low productivity, Small farms, Animal power
Level 2	Second industrial revolution (Industry 2.0) Mass production, assembly line, electrical power	Agriculture 2.0 Supplemental nitrogen, Use of synthetic pesticides, and fertilizers, More efficient specialized machines (combustion engines)
Level 3	Third industrial revolution (Industry 3.0) Automated production, electronics, computers, IT, first PLC system	Agriculture 3.0 Public use of military-GPS, Variable Rate Application (VRA), Telematics, Data management
Level 4	Fourth industrial revolution (Industry 4.0) Fusion of virtual, digital, physical, and biological sphere (CPPS) Convergence of technologies: IoT, AI, Big Data, Blockchain, AR, simulation, etc.	Agriculture 4.0 Cheap and improved sensors and actuators, Low-cost microprocessors, High-bandwidth cellular communication, Cloud-based ICT systems, the use of disruptive technologies such as Big Data analytics, Blockchain, etc.

In essence, the astonishing contributions of Agriculture 4.0 towards Sustainable Development Goals includes; (1) improvement of livelihoods, (2) food sovereignty and adequate nutrition, (3) impact on the rural–urban migration dynamic, (4) Closing the technological divide among country, companies or societies, (5) intensification of sustainable production, and sustainable resource management (Valle & Kienzle, 2020).

4. The Key technologies in Agriculture 4.0

In this study, 119 published paper were analyzed based on the previous study by (Bongomin, Yemane, et al., 2020). This involved counting and ranking of technologies with the mentioned application areas in papers published in the fields of Agriculture or food systems. The study was done on the application of 11 disruptive technologies in agri-food systems. The Pareto analysis was used to locate the major technologies. From the Pareto chart (Figure1), 5 key technologies were identified which includes Internet of things (IoT), Drones, Blockchain, Big Data, and Robotics.

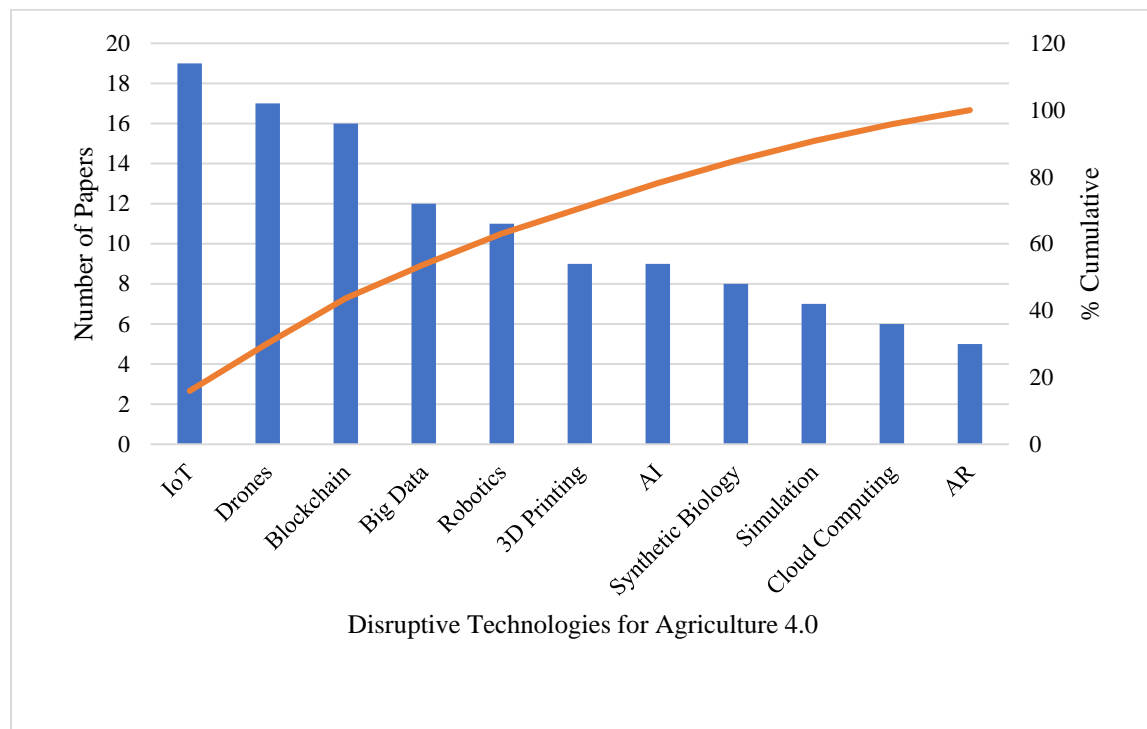


Figure 1. Identification of key disruptive technologies
AI-Artificial Intelligence, AR- Augmented reality

5. Applications of disruptive technologies in Agri-food

5.1 Internet of things in Agri-food

Internet of things (IoT) have been majorly applied in monitoring of crop, soil, irrigation, weather, remote sensing, machinery, farm facilities, and field or environment, livestock, dairy, greenhouse condition and water quality, yield forecasting and prediction, and animal husbandry

(e.g. smart cow farm, smart chick farm, etc.) (Ayaz, Member, & Member, 2019; Diamantoulakis et al., 2020; Pathak et al., 2019; Villa-Henriksen, Edwards, Pesonen, Green, & A, 2020). A number of researchers have also cited the application of IoT in documentation and traceability, agri-supply chain management and security, and agricultural education (Elijah, Member, & Rahman, 2018; Gunasekera, Navas, Vasuian, & Bryceson, 2018; Villa-Henriksen et al., 2020). Furthermore, the application of IoT in crop disease and pest management, fertilization, fertigation and chemigation, crop spraying, intrusion detection in agriculture fields have been reported (Ayaz et al., 2019; Roy & De, 2020; Thakur, Kumar, & Vijendra, 2020). The IoT has also been heavily applied in farm tools or equipment management including IoT-based agricultural machinery (Elijah et al., 2018; R. Zhang, Hao, & Sun, 2017) and IoT-based irrigation control systems (Roy & De, 2020; Thakur et al., 2020; Villa-Henriksen et al., 2020). It has been applied in soil sampling and mapping (Ayaz et al., 2019), and weather prediction (predicting the rainfall) (Roy & De, 2020).

5.2 Drones in Agri-food

A number of researchers have reported the application areas of drones in supervision or precision agriculture, crop monitoring, harvest prediction or estimation and optimization, yield forecast and management, vegetable indices extraction, and variable rate prescriptions in agriculture (Bigliardi, Bottani, & Casella, 2020; Diamantoulakis et al., 2020; Nakshmi, Hemanth, & Bharath, 2020). The application of drones in crop spraying or sprinkling (fertilizers, pesticides, herbicides), efficient scarecrow for birds and insects, disease detection or health assessment and control, pollination, 3D crop modeling have been reported in vast studies (Ahirwar, Swarnkar, Bhukya, & Namwade, 2019; Diamantoulakis et al., 2020). Drones have also been applied in planning, production and disaster management, and insurance (agriculture claims management) (Hagera, Krishna, & Anuradha, 2018; Sylvester, 2018). The application of drones in analyses of soil profiles, field, weed presence, nutrient profile, moisture, plant health, fungal abundance and drainage have been cited by a number of researchers (Ahirwar et al., 2019; Diamantoulakis et al., 2020). Drones have also found their application in ariel planting or seed sowing, field-level phenotyping, crop irrigation (Ahirwar et al., 2019; Probst, Pedersen, & Dakkak-Arnoux, 2018), and frost protection (Frankelius, Norrman, & Johansen, 2017).

5.3 Blockchain in Agri-food

Blockchain technology has been mainly applied in food and agricultural traceability, smart contract and crop insurance, food trade, land governance and registries, financial services in agriculture, transport and agro-logistics, and agricultural supply chain supervision and management (informative) (Kamble, Gunasekaran, & Sharma, 2019; Mirabelli & Solina, 2020; Xiong, Dalhaus, Wang, & Huang, 2020). Further, blockchain has been used in food integrity, food safety (Kamilaris, Fonts, & Prenafeta-bold, 2019), waste reduction, and environmental awareness (C. Zhang & Liu, 2019).

5.4 Big Data

The Big Data are being used in intelligence agriculture, remote sensing, crop yield prediction and crop selection (Prasad, 2019; Tantalaki, Souravlas, & Roumeliotis, 2019). Applications of Big Data in crop or farm planning and management, agricultural policy and trade, farm-to-fork traceability, and agri-food by-product supply chain management have been cited in literature (Delgado, Jr, Roberts, & Vandenberg, 2019; Guo & Wang, 2019). Further, the application areas of Big Data includes crop disease prediction, weed detection, and plant breeding

(Shakoor, Northrup, Murray, & Mockler, 2019; Tantalaki et al., 2019). Tantalaki et al. (2019) has been reported the application of Big Data in weather forecasting and estimation of soil components, temperature, and soil moisture content.

5.5 Robotics

The robotics technology has been heavily used in weed detection and control, target spraying, pest and disease monitoring and control, pruning, thinning, mowing, pollination, fertilization (Mitra, 2019; Steward, Gai, & Tang, 2019; Vougioukas, 2019). The applications of robotics in harvesting (picking of fruits), crop status monitoring, counting crops, classification plant species have also been reported by large number of researchers (Albiero, 2019; Lampridi et al., 2019; Mitra, 2019). Robotics technology has also been used in seeding, sowing and transplanting, phenotyping, land tilling (ploughing, harrowing, rototilling and cultivating), and soil and field analysis (Albiero, 2019; Proskokov, Momot, & Nesteruk, 2017).

The applications of robotics in autonomous navigation (field layout planning, vehicle route and motion planning), computer vision, remote-control systems (Albiero, 2019; Vougioukas, 2019), and irrigation systems have been cited in many studies (Albiero, 2019). Robotics has been used in livestock management (dairy cattle, pigs, chickens), milking animals, removing waste from animal cubicle pens, carrying and moving feedstuffs, manipulators and transportation (Bechar & Vigneault, 2016; UK-RAS Network, 2018). Furthermore, robotics has also been applied in labelling and tracking of food products (UK-RAS Network, 2018).

6. Conclusion

The present paper has identified the key disruptive technologies transforming the current agri-food systems. However, the result may not depict the real-world situation because the study was based on literature search only which has been limited by the published information. Nonetheless, the study gives the insightful understanding on how disruptive technologies are being adopted in agri-food systems. In essence, a single disruptive technology does not define Agriculture 4.0 but the interaction or convergence of several technologies in agri-food gives the meaning of Agriculture 4.0. The study divulged the need for extensive research to expand the application areas of disruptive technologies in Agri-food systems.

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