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Industry 4.0 Approaches in Food and Bio Industry: Recent Developments and Future Trends

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Abstract

The application of the Industry 4.0 concept is essential to increase the productivity and efficiency of industry that includes food manufacturing, bioprocessing, retailing, marketing, and so forth. With Industry 4.0, food industrial processes can also be optimized and handled in a coordinated manner. Industry 4.0 has pioneered the communication of industrial objects with technological elements. However, Industry 4.0 includes high level of uncertainty and complexity. Therefore, more research is needed related to Industry 4.0 in today's fast changing environments. The primary aim of this study is to present the future avenues of research related to food industry and Industry 4.0. The paper provides good opportunities for further studies of digital enablers in Industry 4.0. In the paper, four key digital enablers including internet of things, cloud computing, additive manufacturing and 3D printing, industrial big data are taken into account. This paper can help researchers to determine potential areas requiring the essential research in the field of application of Industry 4.0. To improve productivity and resource efficiency, Industry 4.0 tools (e.g. artificial intelligence) can also be integrated into precision agriculture that enhances the circularity of food systems.

Keywords: *Industry 4.0; Food and bio industry; Internet of things; Cloud computing; Additive manufacturing; 3D printing.*

1. Introduction

In today's industrialized world, food industry is one of the primary sectors to provide foodstuff to satisfy the increasing demand. Food industry is responsible for nutrient supplying from farm to dish in the best way possible. Food processing, fermentation, packaging, safety, storage, marketing, and shelf-life are among the area of interest in the food industry field. Although food industry is a primary sector for world's economy, food companies need to cope with the low price pressure on food materials, environmental risks on food production and constant need for high technology and innovation in production systems. In this respect, food companies invest in research and development to reduce food costs and eliminate food waste. Beside production technologies, production trends constantly change as people focused on healthy eating, customized and fresh food products. To remain competitive in food and bio industry, the data of personal preferences about food consumption is of crucial for food and bio companies. At this point, Industry 4.0 can be used to meet these needs mentioned above.

Industry 4.0 was born with a need to meet requirements of today's globalized world in which the three first industrial revolutions are linked to mechanical power (Industry 1.0), mass production (Industry 2.0) and digital revolution (Industry 3.0) [1]. Due to the augmentation of the overall standards of industrialization, informatization and manufacturing digitization, there has been a growing need to Industry 4.0 for accomplishing efficiency, competency, and competitiveness in global market [2]. The idea of Industrial 4.0 could be described in several ways. Fundamentally, all things related to data are connected with each other. From this perspective, integration of data and information is of crucial [3].

In fast changing environments, implementing Industry 4.0 can be a response to the current challenges. For example, food industry is evolving rapidly and technology plays a crucial role. Scientific and technological improvements facilitate better adaptation of consumer demands to the food processing. In the food industry, constant pressure is available on price and this induces the innovation in food processing technologies. Interconnected machines allow greater flexibility for adaptation of customer demands on specification of food and bio products [4]. Nowadays, food properties, origin, freshness, microbiological and chemical aspects of product safety are important issues for customers. Developing a level of expected quality for all these requirements is complicated. Therefore, the aim of this study is to give an inclusive opinion of Industry 4.0 idea with the purpose of investigating the challenges, issues, components, benefits, and progress in food and bio industry. The paper begins with literature research related to the Industry 4.0 approaches in food and bio industry. Then, digital enablers are explained in Industry 4.0 and the most relevant digital enablers are outlined. Finally, the study ends with the conclusions.

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2. Literature Review

In terms of food and bio industry, Industry 4.0 means equipping food and bioprocessing plants with high technology computers. In this way, machines can understand what is going on around them and connect with each other. Using Industry 4.0 concepts, prediction of production faults and determination of production parameters to adopt changing production standards can be performed. Proposed system can be cost-effective and enables high quality production by providing fast, efficient and flexible processes with the Industry 4.0.

The food industry has provided an important link between the supply chain and farmers. In addition, biotechnology can be employed to increase the quality of the food supply chain for the manufacturing, processing, storage, and so on. Thongpull et al. [5] explained the duty of food analysis and a hand-held fixed multi-sensor system. In the study, hierarchical Support Vector Machine (SVM) classification concept was employed for lab-on-spoon data. Lee et al. [6] portrayed inno-service ideas cyber-physical frameworks from each the problem-analysis aspect and resolution-analysis perspective. In addition, they presented the ideas of cyber-physical systems from each the problem-analysis facet and resolution-analysis perspective. The paper was supported the varied outputs obtained from a wise IoT-based commerce district development project conducted in Taiwan. Silva and Silva [7] proposed an Ipanera, scalable Internet of thing (IoT) design to regulate the class of water of Aquaponics and Hydroponics design that enable Industry 4.0. The proposed methodology showed that the inspection of water quality was affected by sticking to Industry 4.0 standards. For water quality control, the requirement of fuzzy logic controllers was analyzed. In addition, the necessary components were defined to successfully implement Industry 4.0 in systems. Pilinkienė et al. [8] presented a case study of European Union food industry by modeling completely different supply network situations, and enforced a fight strategy supported the Industry 4.0 concept. The paper used lean manufacturing and Radio-Frequency Identification (RFID) technology to increase the efficiency of supply chain. In the study, inefficient transport, storage and recovery operations for the supply chain were analyzed. Kocsis et al. [9] developed a smart service using the principle of Industry 4.0 and IoT. Furthermore, an autonomous grocery delivery fleet was considered. Autonomous vehicles were used to deliver grocery in urban areas. In proposed smart service concept, products were firstly ordered. Then, an electric vehicle was used for autonomous transportation. Considering the customer availability and traffic conditions, route rescheduling was made during the transportation.

Computer-based tools can be used to improve the current food system. Tufano et al. [10] designed centralized kitchen using computer-based multidisciplinary decision-support tool. Proposed decision-support system enabled food service managers to configure food service production plant while emphasizing the interdependencies between decisions and decision-makers. Industry 4.0 methodology was developed by Bakir et al. [11] for small and medium-sized enterprises. The proposed solution offered a network of heterogeneous industrial plants and processes with low costs and low effort. In addition, more transparent and reliable production can be obtained from proposed system thanks to the related and structured data sets. Demartini et al. [12] proposed the methodology of manufacturing value modeling to identify which factors have an effect on the utilization of Industry 4.0. Considering the Industry 4.0 approach in the food industry, various steps were identified and prioritized in the food sector.

Mantravadi et al. [13] presented the information sharing between a wholesaler and meat-manufacturers. To ensure critical product-centric data for wholesaler, the system of manufacturing operations management can be used. The interdependencies of the enterprises were explained in the study. Also, enterprise integration was described in the Industry 4.0 context. Simon et al. [14] proposed a new model considering Industry 4.0 standards. The proposed model was related to customized mass production management in the food industry. In the model, an entire product range was manufactured without changing the production line. Furthermore, the production of fruit yoghurt was given an example. Ahmed et al. [15] presented the characteristics of software defined networks taking industrial automation into consideration. The new network increased the scalability and efficacy of the network. In the study, two approaches were also suggested for flow formation. Moreover, Monte Carlo simulation was employed to verify the analytical model. Gružauskas et al. [3] presented that by applying the autonomous vehicles technique, CO_2 emission levels can be minimized. In the study, the relationships between sustainability and cost performance were explained. Furthermore, Industry 4.0 methodology has been discussed in the process of developing a plan for productivity.

To improve productivity and resource efficiency, Industry 4.0 tools can be integrated into precision agriculture [16]. For example, Valecce et al. [17] proposed the IoT based system for smart agriculture. Miranda et al. [18] developed new technologies using sensing, smart and sustainable product development reference system. In the study, production life cycle of agri-food was defined. In turn, Agri-Food 4.0 which involves automation, networking, and digitalization was launched. The value of renewable energies and the use of capital in the sector were also stated.

Blockchain technology is a new digital technology to ensure data integrity and prevent tampering. Zhao et al. [19] presented traceability system that applied blockchain technology in agri-food. To improve knowledge sharing and services among members in agri-food chain, various blockchain technologies were utilized. In addition, blockchain technology can be combined with IoT and big data to increase privacy, transparency, and efficiency in agri-food information security. Also, the challenges of blockchain were analyzed using a holistic perspective. Furthermore, future research directions were identified to implement blockchain in agri-food value chain. Kamble et al. [20] employed interpretive structural modeling to define the relationship among various factors. In addition, the decision-making research and assessment laboratory (DEMATEL) was used to measure the digital impacts of the quantitatively selected variables. In the report, increasing obstacles in the retail that influences the integration of IoT were found. Tanrıseven et al. [21] presented the concepts to design future kitchens. Energy-saving induction-constructed food processing has been developed for automated kitchens. The proposed kitchens had many novelties including IoT, adaptive power adjustment, and augmented reality technology.

In literature, researches on Industry 4.0 presented the importance of integration of technology to provide a great opportunity for implementations in food and bio industry. For example, Nukala et al. [22] focused on the utilization of IoT in food chains. The study addressed core IoT supporting technology such as cloud computing, wireless sensor networks, recognition of radio frequencies, and data analytics. Luque et al. [4] presented the bibliographic review related to Industry 4.0 in the food industry. The study stated that Industry 4.0 based framework is necessary for not only the industry in general, but also for Andalusian food industry. Ojo et al. [23] studied and evaluated the essential components of Industry 4.0 and efficient management of the food chains. A case study was also discussed on the food supply chain network, which requires Industry 4.0. The importance of the integration of Industry 4.0 was given. Furthermore, the effect of Industry 4.0 on food supply chain was clarified. Introini et al. [24] presented a literature review related to the implementation of Industry 4.0 in the traceability of the food chains. Hasnan and Yusoff [25] focused on the technological advancements that include Industry 4.0 in the food industry. Bader and Rahimifard [26] explored the advantages and disadvantages of industrial robots in food sector. Also, the future projections of industrial robots were outlined for higher uptake.

It is very critical for any food company to cope with its competitors in changing business environment. There are still many unanswered questions about how Industry 4.0 integrated with food and bio industry. Though technologies for Industry 4.0 are of great concern to both academics and professionals, the growing body of study on food manufacturing and Industry 4.0 remains scarce. There is no clear approach accessible in publications to work well for all kinds of issues in the food industry. Therefore, academicians and practitioners are tried to find systematic way for food industry to integrate Industry 4.0. The connection between the food manufacturing and Industry 4.0 is discussed throughout this article, taking into account four main technology enablers. In addition, three important questions are answered as follows. Which digital enablers are widely used in food application? Which method(s)/system(s)/tool(s) are widely used by digital enablers? What areas should researchers explore in digital enablers in Industry 4.0? The suggested review adds depth to the Industry 4.0 in food and bio industry. It can provide an attractive opportunity to determine the future research for this field.

3. Basic Digital Enablers in Industry 4.0

Industry 4.0 contains many disciplines that influence each other. Luque et al. [4] presented the most proper digital enablers in Industry 4.0 including IoT and cloud computing, additive manufacturing and 3D printing, industrial big data, vision technologies, automation and intelligent robotics, and cybersecurity. In this paper, four most proper digital enablers in Industry 4.0 are analyzed. In the following subsection, each digital enabler is briefly explained. In addition, the relationship between digital enabler and Industry 4.0 is given.

3.1. IoT

Internet is used for various tasks such as web browsing and social networking applications. Furthermore, internet is important to access the global information and communication infrastructure. In addition to internet use, embedding of electronics into everyday physical objects creates new opportunities for the Information and Communication Technologies (ICT) sector. The term IoT is broadly used within such perspective [27]. IoT has a big impact on several aspects of everyday-life and behavior of potential users that can be considered as its main strength [28]. ‘‘Internet of Things” paradigm is given in Figure 1.

Table 1. *The analysis of IoT in food industry.*

Author(s)	Application	Basic method(s)/system(s)/tool(s) used in the study	
Thongpull et al. [5]	Food Analysis	• Intelligent Cognitive System with Self-X, • Hierarchical SVM, • Automated Feature Selection	• use advanced magnetic induct
Ray et al. [29]	Fruit Quality Measurement	• loT based Cloud Platform, • Ripening Index Chart	• implement the proposed desig
Ruan and Shi [30]	Fruit E-Commerce Delivery	• Learning-by Doing Mechanism, • Interval Comparison Technique	• gather e-fulfillment data
Verdouw et al. [31]	Food Supply Chain	• FIspace Platform Architecture	• quantify the impact of virtuali • use generic technologies and
Shih and Wang [32]	Cold Chain Management	• IoT based Time-Temperature Indicator System, • Critical Control Point Criteria, • Control Charts	• fuse big data mining with the • increase the cool storage prod
Seo et al. [33]	Food Contamination Monitoring	• Pocket-Sized Immunosensor System, • Android Application Program	• use same concept in surveillin • apply same concept to the ma
Wang and Yue [34]	Food Safety	• Information Sharing Model based IoT, • Association Rule Mining, • Apriori Method	• adopt fuzzy set theory, • test the pre-warning system fo
Accorsi et al. [35]	Food Supply Chain	• Simulation Gaming Tool embedding the IoT	• state on the application of pro
Kong et al. [36]	Perishable Food Supply Chain	• IoT enabled Auction, • Cloud Auction Robot Enabled Execution System	• analyze the effects of products trolley chain length, • use big data analytics tools,
Zhang et al. [37]	Perishable Food Supply Chain	• IoT and Cloud Service Platform, • IoT based Information Sharing	• extend the cloud platform
Li et al. [38]	Prepackaged Food Supply Chain	• Extensible Markup Language based Method, • IoT-based Tracking and Tracing Platform	• evaluate proposed system in r • explore data analytics tools to • develop awarning system to re
Wu et al. [39]	Food Manufacturing Line	• PicknPack Research Program	• use data analysis method, • extend the system optimizatio
Desai et al. [40]	Grocery Monitoring System	• Wireless Sensor Network, • ThingSpeak channel	• implement machine learning a • utilize for budgeting the mont
Bonaccorsi et al. [41]	Smart Freezer	• HighChest IoT Devices, • Task Analysis Method	• equip system with a barcode p • increase the energy efficiency • enable mobile access to storag
Meng et al. [42]	Food Packaging Line	• PicknPack, • Industrial IoT System, • Zyre-Based Messaging Protocol	• apply high-level intelligence c
Mededjel et al. [43]	Food Traceability System	• Cloud and Fog Computing, • Electronic Product Code Information Service	• implement the various module of traceability queries
Morillo et al. [44]	Meal Distribution	• Wireless Sensor Networks, • Flooding Routing, • Routing based on Static Neighbors,	• improve the IoT-based monito • improve the App executed on

Table 1. *The analysis of IoT in food industry. (Continue)*

Wen et al. [45]	Food Waste Management	• Management Platform, • Global Positioning System, • Geographic Information System	• assess the stakeholders usin • design the new tags, • use the dynamic and automa • encourage the information-
Kim et al. [46]	3D Printed Food	• Piston Type Extrusion Method with IoT, • Hagen-Poiseuille Equation	• gather further data to constr
Tsang et al. [47]	Food Distribution	• IoT based Route Planning System, • Taguchi Method, • Genetic Algorithms	• focus on other kinds of pha • apply the proposed system t • Integrate more data mining
Liu et al. [48]	Food Traceability System	• Enterprise Oriented IoT Information Service, • Electronic Product Code Information Service, • Trust Service for the IoT, • IoT Directory Service, • IoT Name Service	• integrate digital signature a
Chaudhari and Chandak [49]	Cold Storage Warehousing	• Apache Spark Service, • International Business Machines (IBM) IoT Real-Time Insights, • Watson Machine Learning Service, • IBM Bluemix	• work on the modeling of sy • test proposed system on oth • test proposed system on hig
Chiang et al. [50]	Fish Meat Quality Monitoring	• Complementary-Metal–Oxide–Semiconductor • Simulation	• incorporate proposed chip i
Sundaravadivel et al. [51]	Food Monitoring System	• Smart-Log, • Application Program Interfaces, • Optical Character Recognition Method, • Waikato Environment for Knowledge Analysis	• utilize the proposed system
Sundaravadivel et al. [52]	Food Monitoring System	• 5-layer Perceptron Neural Network, • Bayesian Network-Based Method, • Application Program Interfaces, • Optical Character Recognition Method, • Waikato Environment for Knowledge Analysis	• Integrate Smart-Log with p
Lin et al. [53]	Food Safety Traceability System	• Electronic Product Code Information Services, • MongoDB	• optimize the peer-to-peer n • optimize the consensus algo • set up information clipping
Mondal et al. [54]	Food Supply Chain	• Blockchain inspired IoT, • Proof-of-Object Based Consensus Model	• strengthen the hardware sec
Ray et al. [55]	Fruit Ripening Quality Index	• IoT based Cloud Service	• provide a more compact siz • use dew computing
Jilani et al. [56]	Food Quality	• Labview Program, • Local-Cloud Approach	• use the sensor as an embed
Jagtap and Rahimifard [57]	Food Supply Chain	• IoT based Food Waste Tracking System	• use advanced image proces • eliminate the dependency o
Jagtap et al. [58]	Food Waste Monitoring	• Deep Learning, • Convolutional Neural Network	• overcome various kinds of

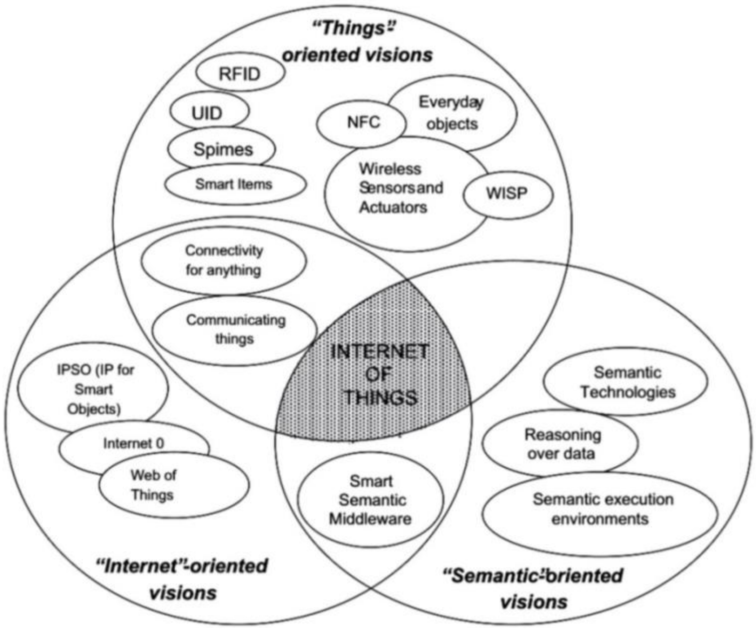

Figure 1. *''Internet of Things'' paradigm [28].*

IoT is widely used in food industry that includes all aspects of related to food such as food manufacturing, storage and processing, food distribution, marketing, and consumption. IoT has the ability to manage the traceability and visibility. Furthermore, it has potential to cope with controllability problems. The more efficient and sustainable food supply chain can be provided with the help of the IoT. It can be said that the food industry is rapidly transformed with the IoT technologies. Food industry is also becoming more advanced, sophisticated, and efficient to cope with the challenges of food security, food safety, and food quality [59].

While many studies have been conducted on usage of technology in the food sector, there is still the need to frame it in the whole value chain and towards the IoT perspective. The food application of IoT, basic method(s)/system(s)/tool(s) used in the study and future research direction are given in Table 1 to provide better understanding of IoT in food industry.

3.2. Cloud computing

Cloud computing can be described as a platform for fast and on-demand customer-friendly connection to a shared database of programmable computer resources. It is seen as the development of different type of technologies that are combined to alter the organizational approach for building information technology infrastructure of organizations [60]. To successful cloud computing adoption for your organization, the cloud adoption lifecycle model can be employed. It provides guide for organizations to begin thinking about cloud. This model provides a baseline to support your adoption of cloud computing. Details about cloud computing can be found in [61]. Google, Amazon, and Microsoft are some of large cloud computing information technology vendors. The cloud computing application has increased the information technology expectations of companies. In addition, the utilization of cloud computing can provide substantial and significant economic savings in food industry. The basic method(s)/system(s)/tool(s) used in the study and future research direction are given in Table 2 to provide better understanding of cloud computing in food industry. In Table 2, cloud computing is used in the food recognition system, food traceability, rice mapping, grain warehouse monitoring, food recognition, and food recommender system.

3.3. Additive manufacturing (AM) and 3D printing (3DP)

AM is a process of injecting elements and pieces of manufactured feedstock content into components (parts). The AM processes can be classified as liquid, solid, and powder based types. AM processes offer many benefits. Some of them can be given as follows: (i) no tool design is required, (ii) no separate machines are required, (iii) material waste is reduced and final cost is minimized [62].

3DP is a classical disruptive technique. 3DP has many advantages over other manufacturing methods. Therefore, the using of 3DP gradually increases. 3DP is reckoned to play a significant role through the dramatic increase in resource efficiency. In addition, overall carbon emissions can be lowered. The effect of 3DP can go beyond rebalancing the global economy and transforming the manufacturing process [63].

Portanguen et al. [64] presented the application of AM methods for the development of biobased products. The 3D-printed biobased products were analyzed. The results of the study demonstrated that 3D-printed products continue to further develop and progress. Also, the problems of meat-based food have yet to be solved. The main challenge for the coming years will be the use of 3DP printing to evolve meat products or products that combine alternative sources of protein that remain completely structured without the use of additives. Godoi et al. [65] presented the current 3DP methods for designing food materials. Material supply was used to classify the methods. Multi-component method optimization and comprehensive product review should be assessed to incorporate AM technologies in the food industry. Nachal et al. [66] presented implementations of the 3DP in food processing. The report reviewed latest developments in the 3D food printing, with an emphasis on the characteristics of content supply appropriate for printing and food printing strategies.

Table 2. *The analysis of cloud computing in food industry*

Author(s)	Application	Basic method(s)/system(s)/ tool(s) used in the study	Future research
Pouladzadeh et al. [67]	Food Recognition	• Cloud-Based Virtualization Mechanism, Deep Convolutional Neural Networks, Amazon Web Services	• embed the virtual network computing server configurations inside proposed android application, • use much bigger data for the training algorithm
Cao and Truong [68]	Grain Warehouse Monitoring	• IoT Cloud based Platform, • Not only Structured Query Language (NoSQL) database, • MongoDB/Cassandra	• apply proposed conceptual frameworks for similar areas
Rehman et al. [69]	Food Recommender System	• Cloud Based Food Recommendation, • Diet-Right Model, • Ant Colony Optimization	• focus on the recommendations breakdown for different timings of the day, • consider the amount of nutrition in different food items as per timing and daily needs of the patients, • develop group food recommendation
Liu et al. [70]	Food Recognition System	• Deep Learning-based Model, • Edge Computing-Based Service Computing Paradigm, • Pre-trained GoogLeNet by ImageNet, • Convolutional Neural Network, • Apache HttpClient, • Django Web Development Framework, • Bounding-Box Strategy	• analyze new deep learning algorithms, • integrate proposed system into a real-world mobile devices and edge/cloud computing-based system
Dandage [71]	Food Traceability	• Cloud Service and Web Application Programming Interface (API)'s, • Web-Based Traceability Portal	• develop the government database for public, • develop Web servers and Web API both modern technological web development application to communicate over internet with seamless access, • use Web API as the best way for integration with mobile or other website
Liang et al. [72]	Rice Mapping	• Multi-Year Training Sample Normalization, • Linear Regressions, • Google Earth Engine Cloud Computing Platform, • Classification and Regression Tree, • Analysis of Variance (ANOVA)	• Combine the sample normalization model and cloud-computing geospatial data platforms in similar future projects

The application of AM and 3D printing, basic method(s)/system(s)/tool(s) used in the study and future research direction is given in Table 3. The AM and 3DP are generally applied in product printing, packaging, processing, recrystallization and quality monitoring.

3.4. Big Data

Web technologies, which are recognized as part of the development of ICT, have at any time collected scientific or non-scientific info. The collected data can be used in the research studies as well as in many fields. The concept of “Big Data” has emerged with the rapid increase of data in terms of velocity, variety, volume and the support of technology to produce new solutions [73]. Big data can be analyzed considering four dimensions. First dimension is volume that is related to the scale of data. The second dimension is the velocity at which data is rising and therefore the study of streaming data is challenging. Third dimension is the variety defining the different forms of information to be used for study. Final dimension is veracity that is related to the uncertainty or inaccuracy of the data. In addition to these, value can be utilized to characterize the data quality [74]. Big data analytics lifecycle can be summarized as given in Figure 2.

Table 3. *The analysis of AM and 3DP in food industry.*

Author(s)	**Application**	**Basic method(s)/system(s)/tool(s) used in the study**	
Wu et al. [75]	Food Quality Monitoring	• Smart Cap Liquid Chromatography Sensor, • Network Analyzer	• improve the measured qua
Severini et al. [76]	Food Printing	• Farinograph Test, • Response Surface Methodology, • Texture Analyzer	• perform exact setting of al • analyze the rheological fe variables
Bogue [77]	Food Quality Monitoring	• Micro-Stereolithography Technique, • Network Analyser, • Smart Cap	• investigate 3DP in sensor
Kouzani et al. [78]	Food Printing	• EnvisionTEC GmbH Bioplotter, • Solidworks	• improve health and well-b • improve economic conditi
Mantihal et al. [79]	Food Printing Optimization	• Rotary Screw Extrusion Method, • Controlled Stress Rheometer, • Texture Analyzer,	• develop printability optim • investigate internal supp properties of chocolate
Yang et al. [80]	Food Constructs	• Texture Profile Analysis, • Mean Comparisons, • Nuclear Magnetic Resonance Analysis	• use proposed system for o
Lanaro et al. [81]	Food Printing	• Differential Scanning Calorimetry, • Rheometer, • Image Analysis Program ImageJ, • Simulation	• introduce a screwthread ex • undertake further testing o
Holland et al. [82]	Food Recrystallization	• Pendant Drop Method, • Curve Fitting Approach, • Xray Computed Tomography System, • Median Filter	• test experimental powders • provide the product hardn
Tohic et al. [83]	Food Additive Manufacturing	• Texture Profile Analysis, • Dynamic Oscillatory Rheology, • Confocal Laser Scanning Microscopy	• investigate the fundament sensory attributes
Vancauwenberghe et al. [84]	Food Simulants	• Regression Models, • Central Composite Experimental Design, • Open-Source Computer Aided Manufacturing (CAM) Software Slic3r, • X-ray Computed Tomography, • TA.XTPlus Texture Analyzer Device	• compare the 3DP of more • investigate important prop • validate the prediction me
Kim et al. [85]	Food Printing, Food Ink	• Stress-Controlled Rheometer, • Texture Analyzer, • Confocal Laser Scanning Microscopy	• use Xanthan gum to create
Lee et al. [86]	Food-Ink System	• Scanning Electron Microscopy, • Oscillatory Frequency Sweep Test, • Controlled Stress Rheometer	• analyze the particle size fo • analyze the particle size to
Vancauwenberghe et al. [87]	Food Manufacturing	• Evans Blue Exclusion Staining Technique, • Open-Source CAM Software Slic3r, • TA.XTPlus Texture Analyzer	• explore the formulation by • develop models to improv • address the edibility of the

Table 4. *The analysis of big data in food industry.*

Author(s)	Application	Basic method(s)/system(s)/tool(s) used in the study	
Lukyamuzi et al. [88]	Food Insecurity	• Naive-Bayes, • Neural Networks, • k-Nearest Neighbors, • SVM	• explore web data for studying • explore the proposed approach
Navickas and Gružauskas [89]	Food Supply Chain	• Competitiveness Maximization Methodology	• conduct a deeper analysis, • apply the clustering method to
Geng et al. [90]	Food Safety	• HTML Analysis and Text Density, • Adaptive Method based on Multiple Reference Factors	• employ link based search strat
Alfian et al. [91]	Perishable Supply Chain	• Three Sigma, • Density-based Spatial Clustering of Applications with Noise	• compare the other outlier dete • use the document-based NoSQ
Ji et al. [92]	Food Supply Chain	• Bayesian Network, • Deduction Graph Model,	• apply big data in different area
Irani et al. [93]	Food Security and Food Waste	• Cause-Effect Models, • Simulations, • Fuzzy Cognitive Map	• extend the number of scenario • use Delphi method, • present unpack food waste at a • extend the proposed system to
Singh et al. [94]	Food Supply Chain	• Fuzzy DEMATEL, • Fuzzy Analytic Hierarchy Process, • Fuzzy Technique for Order of Preference by Similarity to Ideal Solution Method	• Undertake similar studies cons food industries, • evaluate the suppliers consider judgment, • applying group decision makin • apply multi-objective optimiza
Singh et al. [95]	Food Supply Chain	• SVM, • Hierarchical Clustering with Multiscale Bootstrap Resampling, • Naive Bayes	• capture a larger volume of twe • perform the proposed analysis
Li et al. [96]	Food Data Analysis	• Mysql Database, • Python + Matplotlib, • Raspberry Pi-based Website	• make different program impro • expand the access to data, • get more data analysis conclus • conduct differential analysis to different schools, • establish a wide range of stude
Mishra and Singh [97]	Food Supply Chain	• Descriptive Analysis, • Content Analysis, • Parsing Method	• use an enhanced list of keywor • employ Twitter analytics for lo • apply to other domains of food
Xu et al. [98]	Nutrition Analysis	• iPlate System Equipped with RFID	• ensure decision support for the • accomplish the whole calculat • use more factors into nutrition
Parvin et al. [99]	Food Security System	• Information and Communication Technology Tools, • Intrusion Detection System, • Semantic Annotation Methods	• validate the applicability of the

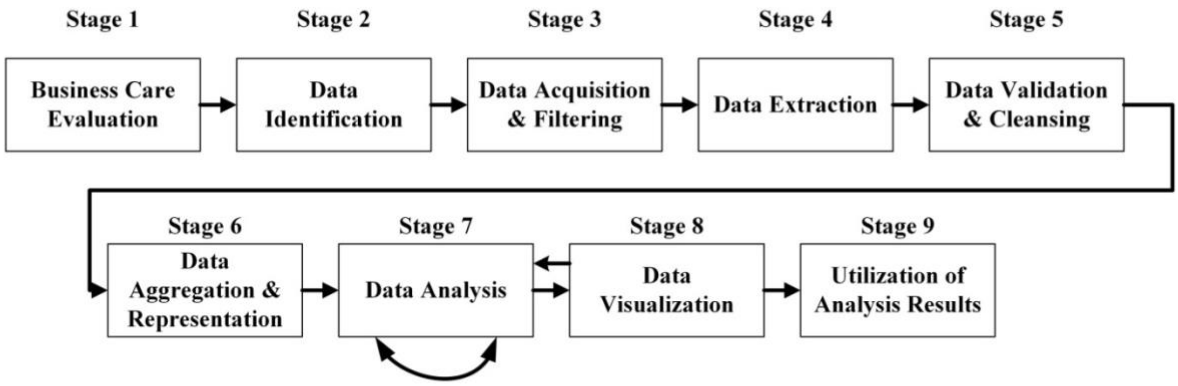

Figure 2. *The analytics lifecycle of big data [100].*

A special infrastructure needs to be designed to create decision support systems at the strategic level of the companies. At this point, data warehouse constitutes the technical infrastructure of decision support systems. The data warehouse ensures an opportunity to assemble non-integrated applications. In the last decade, a new class of data management systems, often referred to as NoSQL systems, has emerged and is developing rapidly today [73]. The reasons for using NoSQL databases are design simplicity, horizontal growth and accessibility. Since the data structures of NoSQL databases are different from relational databases, some operations performed within the database can be faster. Differences between relational databases and NoSQL databases can be found in [101]. Venkatraman et al. [101] presented that NoSQL is more appropriate than Structured Query Language (SQL) in big data analytics applications. Recently, NewSQL databases have been introduced as an alternative to NoSQL and traditional relational databases. NewSQL database systems maintain the basic features of relational databases, but are different from structures exhibited by traditional systems such as Oracle and SQL. Properties of NewSQL databases can be found in [102]. Briefly, the choice of the database may vary depending on the problem structure and the business, and this selection is an important determinant of the overall system outputs.

Food and bio companies have to make use of big data to provide benefit for their customers and employees. Big data can increase the visibility across the industry, ensures an integrated view of customer interaction and operational performance, and provides real-time insights to companies. Integration of big data analytics in systems can enable unprecedented opportunities to food industry for many cases such as traceability system, product security system. Food big data can also help companies provide a credible product quality and new market development.

The application of big data basic method(s)/system(s)/tool(s) used in the study and future research direction is given in Table 4 to provide better understanding of big data in food industry. Big data has been used extensively in food applications such as product security, waste control, raw material, supply chain, cold chain configuration design, perishable supply chain, nutrition analysis.

4. Conclusions

Industry 4.0 is important in industrial environment. The fact that food and bio companies are particularly demanding the transition to Industry 4.0 is emerging from some points that need solutions. These include; discrepancies between planned and actual production times, delays, defective production, inventory control problems, high direct and indirect costs, product perishability problem, and so forth. It is also expected that labor market profile will improve. Also, the high quality products and global competitiveness can be increased with the introduction of Industry 4.0. Thus, it makes a significant contribution to overcoming the challenges of the food and bio industry quickly and profitably. Therefore, Industry 4.0 serves as a gateway to food industry's future.

In this paper, the review for the current and future concept of Industry 4.0 in food and bio industry is presented. Also, the further studies of digital enablers in Industry 4.0 including IoT, cloud computing, AM and 3DP, and big data are briefly given to contribute for the sustainable competitive advantage of the sector. This study provides basic information about the digital enablers and Industry 4.0 that enable us to connect humans, objects and systems to cope with dynamic problem in real-time. This paper helps determine potential research topic related to digital enablers in Industry 4.0 and can be suitable during application of Industry 4.0. The main advantage of this study is that four key digital enablers including IoT, cloud computing, AM and 3DP, industrial big data are analyzed in the field of application of Industry 4.0 for food and bio industry. This study can be extended considering other digital enablers in Industry 4.0 such as vision technologies, automation and intelligent robotics, and cybersecurity. In the light of previous studies, it can be said that future of the food and bio industry will be more flexible, more intelligent, smarter, and more adaptive to ensure the sustainable competitive advantage of the sector. In addition, robotics, autonomous, and unmanned systems make a substantial contribution to overcoming the challenges of the food and bio industry.

Declaration of interest

The authors declare that there is no conflict of interest.

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