

Industry 4.0 in food processing: drivers, challenges and outcomes

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processing

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375

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Abstract

Purpose – In the age of the Fourth Industrial Revolution, Industry 4.0 can increase the productivity and competitiveness of companies in the international marketplace. The purpose of this article is to investigate the drivers for and outcomes of the adoption of Industry 4.0 technologies in the case of a food processing company located in Italy.

Design/methodology/approach – The present work adopted a case study approach by investigating an Italian food processing company to investigate the drivers, challenges and outcomes of Industry 4.0 adoption in the agri-food sector.

Findings – This research highlighted drivers and challenges related to the adoption of different Industry 4.0 technologies. Secondly, it underlined the impacts of Industry 4.0 in terms of firm performance, operations management, human resource management and strategy.

Originality/value – Industry 4.0 technologies remain underexplored from the strategic perspective in the agri-food sector. This article provides preliminary evidence on the digital transformation of food processing companies, with a focus on Industry 4.0. Practical implications for managers, CEOs and entrepreneurs are discussed.

Keywords Industry 4.0, Digital transformation, Agri-food, Food processing, Case study

Paper type Case study

1. Introduction

Agri-food industry responds to the problem of food needs around the world, entails high levels of employment, strongly contributes to economic growth and has relevant impacts on the natural environment. These motives make urgent to find economically, socially and environmentally sustainable productive solutions for the long term (Jambrak *et al.*, 2021). From an historical perspective, food industry has traditionally focused on food integrity and safety (until 1950), enhancing flavours (1950–1980) and health (1980–2000), whereas the new evolutionary phase entails the current and future challenge of promoting the “*health of society*” (Silva *et al.*, 2018; Augusto, 2020). Industry 4.0 represents a group of advanced technologies that can have an important role in this scenario. Such technologies can be applied in various business functions, with strong impacts on products, processes, factories and supply chains (Hasnan and Yusoff, 2018; Manavalan and Jayakrishna, 2019). For instance, Internet of Things (IoT), automation and robotics when introduced in production plants increase the operational efficiency (Bortoluzzi *et al.*, 2020). Big data and analytics can

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be used to categorise data into data-related knowledge that supports strategic decision making at different levels, from operations to marketing (Ferraris *et al.*, 2019; Rialti *et al.*, 2019). 3D printing is typically used to manufacture small batches of complex or highly customised plastic or metal products at relatively low costs (Berman, 2012; Hannibal and Knight, 2018).

The interest for Industry 4.0 has universally increased around the world (Müller and Kazantsev, 2021), with studies emerging in different streams of research and fields of analysis. In agri-food, past studies have suggested that Industry 4.0 could offer practical solutions to typical problems related to quality standards, energy consumption, cost reduction (Hasnan and Yusoff, 2018), but also to mitigate uncertainty and risks characterising the agri-food supply chains (Lezoche *et al.*, 2020). Agricultural computerisation allows energy saving and sustainability increases, whereas smart drone systems and automatic mobile robots are used to monitor the agricultural produce and to carry field crops (Secinaro *et al.*, 2022; Trivelli *et al.*, 2019). However, the applications of Industry 4.0 technologies vary according to the different companies and operational contexts, and the agri-food sector has been less investigated compared to manufacturing (Müller *et al.*, 2018; Manavalan and Jayakrishna, 2019). In particular, studies in the agri-food context on Industry 4.0 technologies mainly consist of literature reviews and theoretical papers (e.g. Rana *et al.*, 2021), mostly focussing on technological applications and functionalities in agriculture (e.g. Trivelli *et al.*, 2019; Secinaro *et al.*, 2022). However, empirical research on the influencing factors and outcomes of the adoption and implementation of such technologies in the agri-food sector is scarce. We aim at contributing to filling this gap through a single case approach (Yin, 2009). Our research aims at investigating the outcomes of Industry 4.0 adoption and implementation in the case of an Italian fruit processing company, which represents a novel context of analysis in relation to the topic. The analysis highlights Industry 4.0-related outcomes at the organisational, strategic, human resource management and economic/environmental levels, but also sheds light on relevant factors have influenced this process.

The paper contributes to advance extant agri-food literature by identifying the outcomes of the Industry 4.0 adoption and implementation process in the case of a medium Italian fruit processing company. In doing so, our findings respond to recent calls and contribute to enrich the scarce empirical evidence on Industry 4.0 in the fruit supply chain (Hasnan and Yusoff, 2018; Oltra-Mestre *et al.*, 2020).

2. Literature review

2.1 Industry 4.0 adoption and implementation

The Industry 4.0 paradigm introduces a new phase of technology-driven innovation for firms (Wee *et al.*, 2016; Culot *et al.*, 2020). Born in the manufacturing context, Industry 4.0 initially identified a group of technological solutions comprising of the internet of Things (IoT), Big Data and analytics (BDA), augmented reality, additive manufacturing, cloud-based systems, simulation, advanced robotics, horizontal and vertical integration, and cybersecurity (Rüßmann *et al.*, 2015; Trivelli *et al.*, 2019). As there is no universally accepted definition of Industry 4.0, other technologies may be considered depending on the sector, such as blockchain and energy management solutions (Culot *et al.*, 2020). At present, some consensus was reached on the core and central role of IoT, which is at the base of interconnection among the different Industry 4.0 technologies, but also represents the common element among smart devices, plants and systems (Culot *et al.*, 2020). Moreover, IoT sets the fundamentals for vertical and horizontal integration, which respectively allow real-time data sharing and analytics throughout different business functions, and extend this possibility across its borders. However, each technology can be implemented in different business functions, leading to distinct outcomes (Chiarvesio and Romanello, 2018).

In the agri-food sector, [Trivelli et al. \(2019\)](#) have identified six clusters of technologies, namely the monitoring, IoT, automation, decision, hardware and laser, underlining the interrelations among them. For instance, the monitoring cluster (e.g. GPS, GIS) is strongly related to the IoT cluster, which refers to the communication of data among machines and devices (e.g. IoT, RFID, sensor networks). Another complementary cluster includes technologies supporting decision making such as artificial intelligence and data mining. In relation to agricultural entrepreneurship, [Secinaro et al. \(2022\)](#) identified macro-topics and themes referring to the value created through new technologies for agri-food entrepreneurs. However, moving from precision agriculture, extant research has scarcely investigated Industry 4.0 applications across other activities of the agri-food supply chain ([Lezoche et al., 2020](#)) and extant works are mainly theoretical. For instance, [Rana et al. \(2021\)](#) have reviewed blockchain applications, whereas [Hasnan and Yusoff \(2018\)](#) have speculated on potential Industry 4.0 applications and impacts in the agri-food supply chain. The scarce empirical agri-food research has so far analysed the opportunities deriving from Industry 4.0 in relation to fresh food products processing in Spain ([Oltra-Mestre et al., 2020](#)), the potential technological innovations in an Italian supply chain of milk, fruit and vegetable products and cereals ([Saetta and Caldarelli, 2020](#)), the technical challenges emerged during the implementation in production of Industry 4.0 technologies in the case of a UK SME producing water crackers and biscuits ([Konur et al., 2021](#)) and the barriers and drivers from a supply chain 4.0 perspective by looking at an Australian food and beverage supply chain ([Ali and Aboelmaged, 2022](#)). However, there are no studies that specifically address the outcomes of Industry 4.0 integration in the fruit processing to date.

The selection and implementation of Industry 4.0 technologies is not an obstacle-free process ([Wee et al., 2016](#)), and there is no single technological solution fitting all firms' needs ([Lezoche et al., 2020](#)). Extant studies have highlighted the existence of perceived barriers and drivers in this process ([Müller and Kazantsev, 2021](#)). Barriers can relate to the lack of finance, technological awareness, collaboration, infrastructure, regulations, knowledge and skills, particularly during the selection of technologies ([Romanello et al., 2021](#); [Manavalan and Jayakrishna, 2019](#)). During the implementation process, change management resistance and skills requirements become particularly relevant for small companies ([Ali and Aboelmaged, 2022](#); [Romanello and Chiarvesio, 2021](#)). Also, some technologies require previous time-consuming processes of knowledge codification and document digitisation that require skilled workforce ([Lezoche et al., 2020](#)). Instead, drivers are strongly related to the expected outcomes ([Ali and Aboelmaged, 2022](#); [Lezoche et al., 2020](#)), such as increased productivity, flexibility, mass customisation, environmental sustainability, reduction of time and cost to market, and quality improvements ([Culot et al., 2020](#)). In addition, Industry 4.0 can also influence value creation and capture mechanisms ([Wee et al., 2016](#); [Rüßmann et al., 2015](#)) and product and process innovation ([Oltra-Mestre et al., 2020](#)).

2.2 Industry 4.0 expected outcomes in the agri-food context

Advanced technologies in production are expected to dramatically improve plants' and factories' performance (e.g. operating costs decrease, improved operational efficiency, increased productivity, lowering of production costs), while contributing to reduce electricity, water and heat consumption ([Borowski, 2021](#)), making productions more economically and environmentally sustainable ([Borowski, 2021](#); [Jambrak et al., 2021](#)). Second, in the agri-food context, robotics and automation merged with interconnected machines are expected to increase the levels of food safety and hygiene, while simplifying maintenance and reducing human injuries ([Saetta and Caldarelli, 2020](#); [Rana et al., 2021](#); [Hasnan and Yusoff, 2018](#)). In the food processing industry, IoT, alert systems and smart industrial robots endowed with cameras and inspection systems can be used to identify risks and abnormalities, improve food quality ([Manavalan and Jayakrishna, 2019](#)) and ensure the fulfilment of food safety

standards (Hasnan and Yusoff, 2018). BDA could allow predictive maintenance and diagnosis to service machines and plants (Saetta and Caldarelli, 2020), but also help tracking and forecasting the shelf life of the items and estimating the expiry at real time (Manavalan and Jayakrishna, 2019). Moreover, BDA could help firms finding the right balance between the energy spent and the level of products' transformation and necessary costs, in contrast with the established trend that suggests that companies should try to maximise the shelf life of food products at any cost (Augusto, 2020). In addition, sharing and analysing data across the firm boundaries will increase efficiency, sustainability, flexibility, agility and resilience throughout the supply chain, from farmers to the final customers, contributing to reduce the uncertainty and risks related to products (e.g. shelf life, food quality and safety), processes (e.g. supply lead times, production, resources needed), markets (e.g. demand requirements, price competition) and the environment (e.g. weather, diseases, regulations) in the agri-food sector (Lezoche *et al.*, 2020). The flexibility and reaction speed of industrial and logistical systems merged with BDA could improve the interpretation of customers' demands and needs in terms of tastes and information accessibility (Ali and Aboelmaged, 2022; Rana *et al.*, 2021; Oltra-Mestre *et al.*, 2020; Hasnan and Yusoff, 2018). QR codes and radio frequency identification (RFID) systems can be used to track food materials in the food supply chain, to increase efficiency of stock control (Saetta and Caldarelli, 2020) or to allow consumers to access information on the country of origin and the ingredients included in finished products (Hasnan and Yusoff, 2018). In this respect, blockchain is still unexplored (Rana *et al.*, 2021), but could effectively enhance data sharing, security, anonymity, trust and decentralisation at all levels (Lezoche *et al.*, 2020; Saetta and Caldarelli, 2020), and could increase products' traceability across the supply chain (Ali and Aboelmaged, 2022; Hasnan and Yusoff, 2018; Rana *et al.*, 2021). Blockchain could allow consumers tracking the food's origins and movements across the supply chain, assessing the environmental impact, ethical aspects and quality, with positive returns in terms of consumers' trust, brand reputation and reduced food fraud (Saetta and Caldarelli, 2020). Overall, optimisation through Industry 4.0 is expected to lead to more sustainable data-driven supply chains — supply chain 4.0 (Lezoche *et al.*, 2020) by reducing supply-demand misalignments (Ali and Aboelmaged, 2022).

Last but not least, 3D printing is now used to manufacture small, customised batches of complex metal or plastic products at lower costs. Food 3D printing is still in an experimentation phase (Jambrak *et al.*, 2021; Augusto, 2020). For instance, Foodink is a 3D printing restaurant offering a gourmet experience of 3D printed food (<http://foodink.io/>). Although food 3D printing for industrial purposes is considered futuristic, it might be promising as a green and clean production technology to produce customised products for specific customers' needs (e.g. vegan).

3. Research methods

3.1 Research context

Trentofrutta is a food processing company located in Trento with a factory of 38,000 square meters. With 177 employees and a turnover of about 50 million euro, its main activities include: (1) processing fruits into semi-finished products for industry and (2) contract filling of finished products into bottles and pouches.

Initially labelled Cremogem Spa, the firm was established in 1961. Five years later, the firm changed the name and added a new investor, who gradually acquired stakes in the company until he finally became the sole owner in 1971. The company was then acquired in 1988 by a German group, who, in addition to financial capital, endowed the company with a new name, Trentofrutta, and a strategic business plan aimed at extending the fruit processing operations and expanding the business abroad. Nowadays, Trentofrutta belongs to a family group of enterprises, which includes other complementary medium companies focused on specific fruit processing activities.

The firm mainly operates in the business-to-business context with two main business lines. The first and traditional business encompasses the production of fruit and vegetable-based semifinished products for industry. This business line mainly relies on the establishment of long-term relationships with its customers, such as leading players in the international food industry. The second business line is more consumer oriented, as the firm produces finished products in glass and pouch formats as a white brand for leading beverage and baby food brands and large-scale Italian and European distribution clients. With this second line of business, the firm sells products mainly in Germany, Italy, UK and Holland.

Trentofrutta relies on fruit purchasing, while the rest of the chain is short and internalised (from fruit processing to pouch filling and packaging). The short chain sourcing reflects the decision to ensure high levels of safety and quality and makes the business more environmentally and economically sustainable. Fruit is sourced nationally (except from tropical fruits). The firm has established sustainable fruit supply chains, particularly for biological product lines, while it has a “controlled” chain where firm specialists and agronomists perform strict controls on the use of pesticides among suppliers’ and agriculturists’ activities. This is fundamental to ensure that semi-finished processed fruit can be used for baby food purposes. Over the years, the firm’s policy relied on selecting suppliers and establishing long-term relationships with reputed suppliers (e.g. cooperative firms with long-lasting traditions).

The firm stands out for investments made in digitalisation and Industry 4.0 over the last five years, also in consideration to its medium size. Some implementation processes are still in progress, such as the introduction of additional digital measurement systems in production, new internal data sharing systems, predictive maintenance tools and other innovative technical solutions. Table 1 describes the evolution of investments in digital transformation over the last years.

Since 2015, the firm experienced a change in its vision strategy and the owner and the CEO initiated the digital transformation and firm repositioning in the marketplace. First, they fostered and spread a strong customer orientation, e.g. by developing a new packaging design to respond to customers’ requirements. Second, they initiated a process to reposition the firm in a medium-high market segment by introducing the pouch production lines, which were considered more profitable and appealing for customers. Since then, the digital strategy was planned and developed for group enterprises, by leveraging synergies both during the selection and implementation of technologies. As illustrated in Table 2, the digitalisation process started in 2015 with the new management software and information and communication technology systems, followed by advanced robotics and IoT in one plant, a brand-new Industry 4.0 plant in 2017 and big data collection and analytics implemented over the last two years.

Group firms have implemented the same management software and ICT system, which allowed the interconnection of all business functions within the organisation. Production supervision is supported by laptops and screens through which simply checklist activities and uncompleted tasks. Employees use a key card to access departments and record activity developments, which leads to an automatic generation of production and human resource

Indicators	2015	2016	2017	2018	2019	2020	2021
Own investments in digital transformation and firm re-organisation (million Euro)	0.7	2.8	4.5	2.4	5.6	1.3	4.2
Employees	101	109	150	174	174	175	177

Source(s): Authors’ elaboration

Table 1.
Investments and employees of Trentofrutta over the last seven years

Table 2.

Description of digital and Industry 4.0 technologies adopted or evaluated

Industry 4.0	Objectives	Development stage
<i>Digitalisation process and vertical integration within the organisation (new ICT and management software, screens and i-pads in production)</i>	<ul style="list-style-type: none"> • Communication flows improvement • Optimisation of planning and production • Increased process control • Cost-effectiveness • Food safety and quality increase 	<ul style="list-style-type: none"> • Advanced (since 2015)
<i>Robotisation, machine interconnection and automated controls in the first production line</i>	<ul style="list-style-type: none"> • Operational efficiency • Economic and environmental sustainability 	<ul style="list-style-type: none"> • Advanced (2015, 2017)
<i>Industry 4.0 production plant (automatic and digitalised controls, robots, interconnected machines, connection with other business functions)</i>	<ul style="list-style-type: none"> • Explore its potential • Improve production planning • Strategic analysis to support decision making 	<ul style="list-style-type: none"> • Advanced (since 2018) • Ongoing (since 2020)
<i>3D printing</i>	<ul style="list-style-type: none"> • Food quality • Traceability • Supply-demand alignments 	<ul style="list-style-type: none"> • Under evaluation and waiting for development
<i>Big data analytics in production, and at the strategic level</i>		
<i>Horizontal integration with customers and suppliers</i>		

activity reports. Currently, the firm is introducing the use of iPads in production. Through these investments, vertical integration within the company has been successfully achieved. Vertical integration merged with Industry 4.0 in production allow big data collection and analytics at different organisational levels, from orders to production planning and outbound logistics.

A second group of Industry 4.0 investments pertains to production. In addition to existing production lines for glass filling, in 2015 the top management implemented a continuous and automatized pouch-filling production line (not digitalised). As this choice was rewarding, further investments were made to automatise the palletisation phase and widen the tank after some years. In 2017, exploiting the experience gained through the first implementation, the firm introduced also a second production line for pouch filling, completely automatized, robotised and digitalised in accordance with the Industry 4.0 paradigm. This second production line allows automatic controls also related to quality, hygiene conditions and food safety requirements. In general, the firm also adopts X-ray machines, machines to read QR codes, bar code readers, precision weighting machines and other innovative analytical tools in each production line. 3D printing is used to produce spare highly customised parts or single components for cost and saving purpose.

At the moment, horizontal integration with suppliers (e.g. agriculturists) and customers has not been particularly developed yet. In fact, the level of customers' digitalisation tends to be advanced, whereas suppliers are less prepared for this approach. The firm already digitally stores data on the country of origin of products, but customers and final consumers cannot digitally access information. At present, product, process and firm certifications in addition to regular client audits (through audit, inspections, data requests, complete traceability system) are used to guarantee quality to customers.

3.2 Research design

We adopted a case study methodology (Yin, 2009) to explore relevant factors and outcomes related to the Industry 4.0 adoption and implementation processes, which is a relatively new

topic in the agri-food sector (Hasnan and Yusoff, 2018; Oltre-Mestre *et al.*, 2020). We chose the case study approach because it is useful to “understand the dynamics present within single settings” (Eisenhardt, 1989, p. 534) and is particularly suitable for theory building purposes, also given the relatively new nature of the phenomenon (Eisenhardt, 1989; Eisenhardt *et al.*, 2016; Lyons, 2005; Ferraris *et al.*, 2019). The fruit supply chain has been already adopted as a context of analysis in Italy (Canavari *et al.*, 2010), but not yet in relation to this research question. Single case studies have the advantage of providing rich descriptions of the object of study and revealing aspects of a phenomenon that has so far been inaccessible (Eisenhardt, 1989; Franceschelli *et al.*, 2018; Yin, 2009). We followed a theoretical sampling to choose the single case study. Through an initial screening of agri-food companies located in Trentino Alto Adige, we identified and purposefully selected Trentofrutta, a fruit processing company located in Trento (Italy), because it has an ongoing digital strategy and an ongoing plan of Industry 4.0 adoption since 2015. This company represented a single information-rich case, which we considered unique and revelatory (Eisenhardt, 1989; Eisenhardt and Graebner, 2007), and, given the ongoing digital strategy, guaranteed the initial assessment of outcomes. It provided an extensive description of what is happening in this particular context of analysis (Welch *et al.*, 2011), reconnecting and enriching previous evidence on the fruit supply chain in Italy (Canavari *et al.*, 2010).

3.3 Data collection and analysis

We chose to collect primary data through in-depth interviews with key managers of the company due to the exploratory nature of our study (Eisenhardt, 1989). We gave voice to informants, who were treated as knowledgeable actors. After consulting a general literature on the topic, we developed an interview schedule based on open questions on the Industry 4.0 adoption to allow the raise of novel insights and facilitate theory building (Goulding, 2002). As Industry 4.0, we included technologies proposed by Rüßmann *et al.* (2015) and blockchain following agri-food studies (Lezoche *et al.*, 2020; Rana *et al.*, 2021). The interview protocol consisted of five steps. The first in-depth interview was conducted with the Integrated Management System Manager in May 2021. It lasted about 90 min, was recorded and literally transcribed into text. As our objective was to preserve flexibility to adjust interview protocol based on informants responses (Goulding, 2002), iterative interviews were then collected with the respondent to solve and verify unclear issues and integrate data collection. The second interview was collected in July, the third in August and the fourth in September 2021. The fifth step consisted of collecting feedbacks and integrations with the CEO, production director, and human resource and financial director in August/September 2021. We stopped collecting data when we reached theoretical saturation, hence seeing that additional interviews brought minimal incremental learning (Eisenhardt, 1989). Each respondent separately and individually read the case analysis and findings to ensure fidelity of interpretation and for validation purposes (Goulding, 2002). To avoid retrospective bias, we used different sources to gather data for triangulation purposes, including archival documents (e.g. balance sheets, company policy declarations), websites and press releases. Interviews transcripts and archival data were organised in a firm dossier. We used qualitative techniques to analyse data (Eisenhardt, 1989; Miles *et al.*, 2020). After removing data unrelated to the object of this study, we coded data based on *a priori* codes aligned with the research question (Miles *et al.*, 2020). According to Miles *et al.* (2020), during data analysis, other codes emerge inductively compared to the initial list. Then, we proceeded with data theming by clustering data according to commonalities, and this facilitated the synthesising and emergence of concepts and relationships between variables (Eisenhardt, 1989; Eisenhardt *et al.*, 2016). This analysis led to the creation of tables and figure included in this article.

4. Findings

The outcomes of digitalisation and Industry 4.0 technologies were observed at different levels of the organisation, as illustrated in Figure 1. The Industry 4.0 technologies positively influenced product quality, process effectiveness and strategic planning capacities.

4.1 Economic and environmental outcomes

At the economic and environmental levels, automation, digitalisation and Industry 4.0 technologies led to a variety of outcomes including *productivity and operational efficiency increases*, and *waste, energy consumption and CO₂ emission reduction*, increasing the economic and environmental sustainability of the firm. For instance, vertical integration allows to optimise production planning, with positive impacts in terms of waste reduction and energy saving.

The photovoltaic system on the roofs allow to meet average internal energetic needs. We have four steam generators inside the thermal power station and a water purification system. We also self-produce what we need (e.g. spare parts) through 3d printing for instance. This is what characterise our company: we exploit internal technologies and employees' skills to solve problems, also looking at economic and environmental sustainability. All these plants are interconnected and allow data analytics and energy consumption optimisation. (Third interview)

Compared to the more traditional production line, the Industry 4.0 plant for pouch filling enabled *better controls of production processes* and *throughput time and lead time reduction*. Compared to the non-digitalised pouch filling, the Industry 4.0 plant has a lower average operating cost. Automation and digitalisation partially reduced workforce. Compared to the first line, this production plant also includes robots and automatic systems performing 100% controls on quality and hygiene conditions. This *improved hygiene conditions in the continuous line*, while initial positive impacts were noted on *food quality and safety*.

4.2 Organisational outcomes

The organisational level emerges in relation to vertical integration across business functions and Industry 4.0 in production, which allowed rapid information and communication flows within the firm and across its borders (e.g. with customers). Digitalisation through the new management software increased flexibility and problem-solving capacity within the

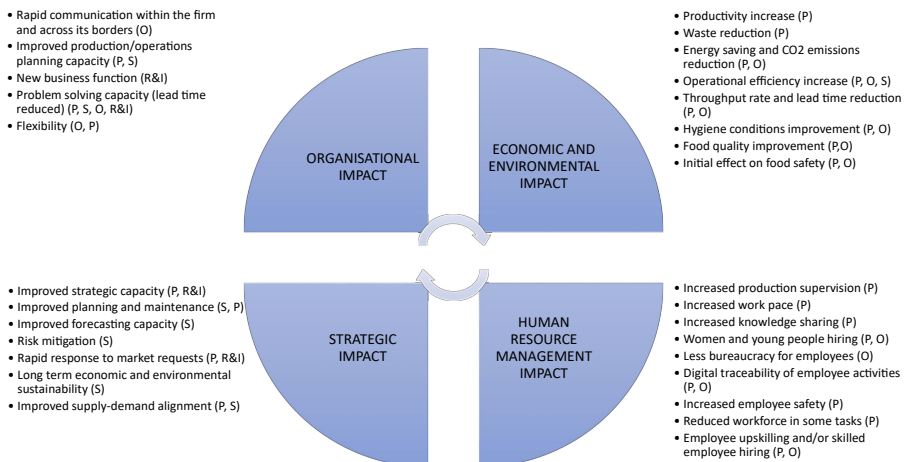


Figure 1. Industry 4.0 outcomes

organisation, even if requiring organisational and cultural changes as a counterbalance. For instance, digitalisation processes required resource- and time-consuming procedures of knowledge codification. Also, some settings of the new management software were initially perceived as cumbersome and required to be customised and tailored on the necessities of the organisation. This was made possible by the department created *ad hoc* to support the digital transformation of the firm.

A new business function was created to serve digitalisation purposes: an internal engineering department specialised on technological advancements, in addition to the engineering department for internal maintenance of plants. Both departments benefit from the support of the ICT department, which is located in the group company but serves the whole group. These departments and the digital knowledge and skills accumulated allowed the incremental implementation of other technologies (e.g. BDA), while containing the costs and expenses. This team designed and customised the lines according to specific production requirements and was highly receptive to technological advances.

4.3 Human resource management

As regards the human resource management level, the adoption of Industry 4.0 influenced recruitment processes (new employees, new skills, women, young), current job positions and tasks' characteristics (fewer manual activities, less physical effort, more supervising activities, expected less bureaucracy) and training activities aimed at upskilling/reskilling personnel (organisational culture, digital skills, etc.).

The new hiring procedures, particularly in relation to the Industry 4.0 production plant, resulted into a generational turnover and an increase of female workers. Although employees tend to be reluctant to radical and new digital solutions, young workers showed more adaptability and were able to infuse new competences and skills into traditional practices embedded in the organisation. This became an asset for the firm. Also, operational activities in the Industry 4.0 plant required different skills such as concentration, precision and control rather than hard physical work. Consequently, in production, most processes have now a shift supervisor and a vice-shift supervisor, who share a knowledge and have complementary skills to guarantee that plants can operate even when the supervisor is unavailable. Competency tends to be more distributed in the organisation and new figures in supervisory and coordination tasks were employed. The new hiring procedures resulted in a higher number of *female workers in supervisory roles*.

The Industry 4.0 production line employees several women particularly in supervisory roles and as "forewomen", whereas the less digitalised business-to-business production line still sees a higher percentage of men. Also, digitalisation and Industry 4.0 led to create new supervisory roles, which were often assumed by females. (Third Interview)

New roles in maintenance activities emerged and new figures were hired: e.g. the supply chain coordinator and the HR manager. Other tasks are now performed entirely automatically, such as the pasteurisation temperature now constantly verified. As regards the quality function, initial controls of employees are now stronger in terms of machinery settings, but less necessary on the continuous line as machines automatically signal anomalies. These phases have seen a *reduction in manual work* and *an increase in supervision and coordination activities*. The use of robots and automation in the riskiest processes *increased employee safety*, while increasing the work pace. Also, digitalisation allows to trace employee activities, decreasing their daily bureaucratic activities and *simplifying* their everyday tasks.

The aim is to dramatically reduce bureaucracy for employees, who would be extremely satisfied if they do not need to fill out paper documents anymore (e.g. vacation plan, activity log), and most operations' results would be digitally generated. (First interview)

Training activities encompassed the strong upskilling and reskilling of personnel, in addition to a program of digital-skills training activities for new employees. In the Industry 4.0 plant, several employees were moved from operational to supervisory activities, and specific training activities were necessary to upskill human resources. Since 2015, the top managers accompanied digitalisation with specific training activities and hired an HR manager, who supervises teams, assesses employees' competences and skills in relation to the assigned tasks, and identifies appropriate training paths. This activity was also supported by an external psychologist, who helped employees to win resistance to change.

4.4 Strategic outcomes

The digitalisation of production timesheets permits the monitoring of time necessary for maintenance, washing and core production, with strong strategic returns in terms of strategic decision making.

Each working hour is detailed in terms of order, working activity, and task, giving top management the opportunity to effectively calculate and analyse the cost of each activity and order. Big data collection and analytics has revealed an exceptional instrument to optimise planning and production, and – overall – to support decision making at the corporate level. (Third interview)

The digitalisation of processes enables the generation of statistics that are used to: (1) *accurately plan production and resource allocation* among the two business lines, (2) to plan *maintenance activities* and (3) to support strategic decision making at the corporate level. Top management members use big data analytics to *better forecast demand trends and align strategic capacity requirements*, and, eventually, *mitigate risks* related to demand decreases and agriculture uncertainty. This approach allows the organisation to rapidly *respond to market requests*. Further developments are expected from the additional investments made in data elaboration, statistics generation and digital solutions to extract strategic value from data. [Figure 2](#) describes associations among Industry 4.0 technologies and outcomes.

5. Discussion: drivers, barriers and strategies related to industry 4.0

Our results do not deviate too much from manufacturing studies, which had shown that SMEs carefully select and incrementally adopt Industry 4.0 in line with their strategic purposes ([Kane et al., 2015](#); [Chiarvesio and Romanello, 2018](#)). Likewise, we found that the adoption of some Industry 4.0 technologies (e.g. new management system, IoT in production) paved the way for other related technologies (e.g. Industry 4.0 plant, BDA) ([Bortoluzzi et al., 2020](#)). For instance, the new management system first laid the foundations for vertical integration, whereas the repeated introduction of IoT in production created the conditions to deeply integrate and interconnect the different business functions and perform BDA to support strategic decisions. This technological integration also opens the way for a horizontal integration with customers in the next future (see [Table 3](#)). Although barriers emerged during the selection and implementation process (as highlighted in [Table 3](#)), the firm clearly navigated the digitalisation process in an incremental but effective way thanks to the vision and commitment of the top managers. After almost seven years, Trentofrutta has an advanced level of digitalisation and Industry 4.0 and initial positive returns have clearly emerged.

The digitalisation process was made possible by the clear vision who jointly had the owner and the CEO under competitive pressures stemming from the market changes. In line with past evidence (e.g. [Romanello et al., 2021](#)), it also depended on the top managers' attitudes and level of technology awareness that led them to carefully develop a digital strategy to incrementally implement Industry 4.0, also in consideration of the novelty of technologies and the lack of best practices in this sector.

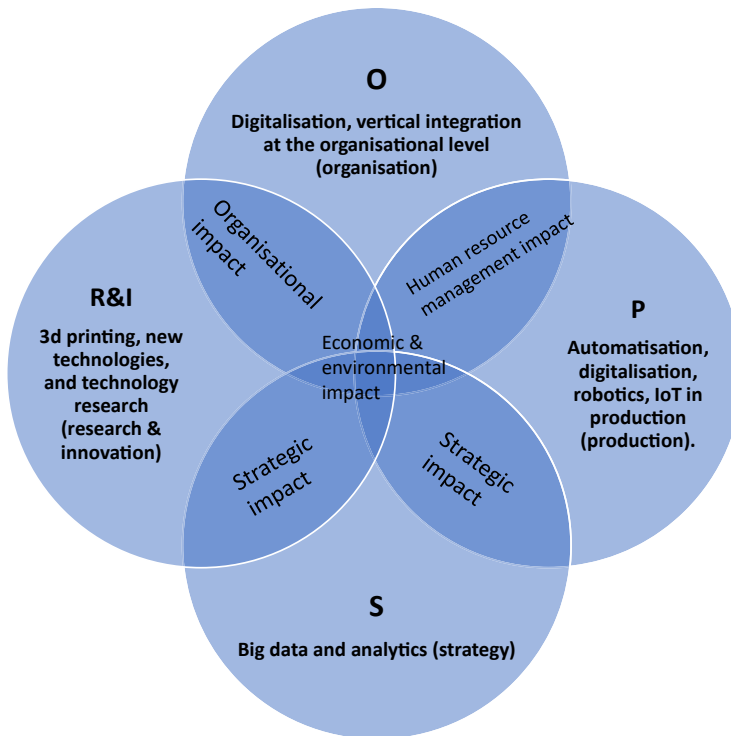


Figure 2.
Industry 4.0
technologies and
related outcomes

The successful implementation was achieved by a learning-by-doing process through which the firm increased its digital skills and found the most suitable technological applications for the business. For instance, BDA were initially adopted to optimise planning and production, but were then found more useful to support strategic decision making. The trial-and-error approach to Industry 4.0 has been found also in the manufacturing context, showing that SME can incur into slowdowns and challenges during this process and may require huge amounts of time and resources before positive returns on performance are obtained (Müller *et al.*, 2018; Bortoluzzi *et al.*, 2020). Even in our case study, although the selection phase was facilitated by the clear vision of top managers, visualising *ex ante* the positive impacts of each technological application remained an issue. However, the alignment between digitalisation and the firm strategy represented a key aspect to rapidly overcome emerging challenges, successfully implement technologies and obtain early positive outcomes (Kane *et al.*, 2015; Bortoluzzi *et al.*, 2020).

Apart from limited public support for training and some national tax benefits, the firm self-financed technological investments. This represented an important economic commitment for the company in consideration to its size and the unpredictability of outcomes. The success was also due to the synergies created among the group companies. Trentofrutta partially benefited from the support of the group company, who shared the ICT department's resources, digital skills and experience, which are invaluable resources in the digitalisation process that is *per se* knowledge- and skill demanding. In this sense, belonging to a group of enterprises partially compensated the limitations of being a relatively resource-constrained medium company and was determinant to overcome the knowledge and skills

Drivers	Barriers	Strategies
<i>Digitalisation and vertical integration</i>		
<ul style="list-style-type: none"> Owner and CEO vision Group digital strategy 	<ul style="list-style-type: none"> Uncertainty and unpredictability of outcomes Challenging <i>ex ante</i> evaluations Wide time range between implementation and results Limited financial resources and digital skills 	<ul style="list-style-type: none"> Gradual learning process Incremental adoption
<ul style="list-style-type: none"> Medium and flexible organisation Limited amount of data to be digitised and stored Easier access to information Better planning capacity 	<ul style="list-style-type: none"> Change management resistance Cultural organisation integration issues <i>Ex ante</i> time- and resource-consuming knowledge codification procedures Difficulties in aligning information across business functions 	<ul style="list-style-type: none"> Group company's shared resources ICT department of group company Digital skills training Psychologist support Knowledge codification procedures settled Tailored technical solutions created by the internal engineering team
<i>Robotisation, interconnection of machines and Industry 4.0 plant</i>		
<ul style="list-style-type: none"> Production optimisation Cost and energy reduction Industry 4.0 training support Tax benefits Expected improvement of planning strategy 	<ul style="list-style-type: none"> Capital-intensive investments Digital skills needed Organisational routine changes required 	<ul style="list-style-type: none"> New internal engineering department creation Industry 4.0 training Upskilling/reskilling of employees Skilled employees hiring
<i>3D printing</i>		
<ul style="list-style-type: none"> Customisation Lead time reduction 	<ul style="list-style-type: none"> 3D CAD design skills required 	<ul style="list-style-type: none"> Specific training Spread 3D CAD design skills and 3D printing knowledge in the engineering team (four people trained)
<i>Big data analytics</i>		
<ul style="list-style-type: none"> Other Industry 4.0 technologies already implemented (ICT management software; IoT in production) 	<ul style="list-style-type: none"> New analytical and statistical skills' needs Difficult <i>ex ante</i> evaluations of applications 	<ul style="list-style-type: none"> Training to improve technology awareness and foster specific skills
<i>Horizontal integration</i>		
<ul style="list-style-type: none"> Customers' advanced digitalisation level Customers' requests for certifications 	<ul style="list-style-type: none"> Organisational culture change Long-term implementation process Unprepared suppliers 	<ul style="list-style-type: none"> Raise level of technological awareness

Table 3.
Drivers, barriers and strategies in relation to Industry 4.0

requirements. In contrast, medium size somehow represented an advantage in the integration of technology throughout the organisation, as large companies tend to have established organisational routines and large flows of stored information that require complex processes to be codified and digitalised.

The implementation of each technology entailed change management issues, which were faced through specific training activities and psychological support. Specific human resource management strategies were deployed to improve inter-organisational communication about the goals and the expected impacts of digitalisation. Also, the reskilling and upskilling of personnel and the hiring of digitally skilled workers were necessary to support this process. For instance, 3D printer is now used to internally manufacture spare/maintenance parts at lower costs and there are four permanent employees able to use additive manufacturing.

Horizontal integration with customers may be required by clients in the future, while integrating with suppliers could be advisable to optimise costs and achieve digital food traceability in the supply chain. IoT could be used to digitally certify and track country of origin, quality, hygiene conditions, facilitating both the fulfilment of law requirements related to contaminants in baby food and facilitate communication with customers and final consumers. Although there are already Artificial Intelligence-based software products specifically developed for food traceability, this approach would require an additional cultural change in the organisation and within the supply chain. This might represent a qualitative leap for the company, which – despite the strict procedures already in place – could oversimplify procedures and improve controls on externalised phases (agriculture). However, most suppliers are not prepared for such level of technological complexity. Additionally, sharing data across the supply chain would require complete transparency among members, while the use of blockchain would entail that each firm assumes the responsibility for potential mistakes as data are encrypted, shared and unmodifiable (Saetta and Caldarelli, 2020; Rana *et al.*, 2021). This might represent the future for this industry leading to a better alignment between supply and demand, but remains a complex process at the moment.

6. Conclusions and implications for theory, practice and policymakers

This work illustrates the successful case of a firm digital transformation. Our study provides empirical evidence on the Industry 4.0 outcomes in a food processing company, underlining that the adoption process was not straightforward because both facilitating and hindering factors emerged throughout the adoption and implementation processes. To be successful, the digital transformation required the total commitment of the top management, who was responsive in developing prompt strategies to overcome the challenges emerged during the implementation process. This is particularly relevant in consideration of the long time-elapse from the initial adoption of technologies and the time when positive impacts emerge. Although this result is aligned with recent manufacturing studies, our research shows that this incremental process is valuable from a long-term perspective as some specific technology-outcomes are expected to be particularly relevant in food-processing, such as the IoT for customer-information traceability or the integration of information flows across the firm boundaries to better align demand and supply. Our firm-level study complements extant works that have so far adopted an agri-food supply chain perspective (Lezoche *et al.*, 2020; Manavalan and Jayakrishna, 2019; Rana *et al.*, 2021) and identifies categories of outcomes that could be tested in different agri-food contexts and larger samples.

From practitioners' perspective, our study suggests that managers must handle the process of implementation of Industry 4.0 by carefully addressing the psychological drawbacks of changes introduced in the organisation. In line with recent reports (Eurofound, 2021), our study shows the importance of two core aspects. First, the early communication with employees, piloting and psychological support, and the human resource management strategies that allowed to overcoming change resistance and foster/source the skills necessary to the process. Second, the alignment between the firm and digital strategy (Kane *et al.*, 2015), which allowed to pursue clear strategic goals and reach satisfying performance returns in a relatively short time.

Due to the various complexities, in our view, firms would be more incentivised to adopt Industry 4.0 if the market formally recognised these efforts, e.g. through an Industry 4.0 certification. Sectoral certification agencies might evaluate the possibility to formally recognise a value added to companies investing in Industry 4.0 technologies aimed at digitalising traceability, food quality, food safety, hygienic conditions, employee safety, and guaranteeing data accessibility and transparency. For instance, sharing data across the supply chain using blockchain entails a high level of responsibility that should be counterbalanced by profits or additional value recognised by customers or final consumers. This might be an interesting aspect to be considered by policymakers operating in this sector.

From a policymaking perspective, public support and innovation policies are, indeed, a driver of technological adoption, such as the lack of digital infrastructure represents a barrier (Eurofound, 2021). Supporting firms both financially and through infrastructure investments is important, while thus remembering that advanced technologies that increase firm productivity tend to reduce the need for low-skilled employees. This explicit support to productivity factors should at least be in part compensated by policies that are centred on human resources. As highlighted by Akyazi *et al.* (2020), future skill requirements in agri-food will mainly relate to data analysis, the use of digital communication tools and Industry 4.0, technologies critical thinking and decision making, and complex information processing and interpretation. Supporting training related to Industry 4.0, and course to re-skill and upskill human resources should be core in policy programs, such as specific educational programs should be centred on the skills requirements emerging in this sector.

Some limitations must be considered when interpreting our findings. This single case study has an exploratory purpose, rather than generalisability of findings. This work focuses on a fruit processing company, whereas future studies are needed to investigate the outcomes of Industry 4.0 among companies operating in different positions of the agri-food supply chain, because mechanisms and outcomes could largely vary depending on production and product types.

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