Chapter

6

Agricultural sciences and revolutions in food production: from the past to the future

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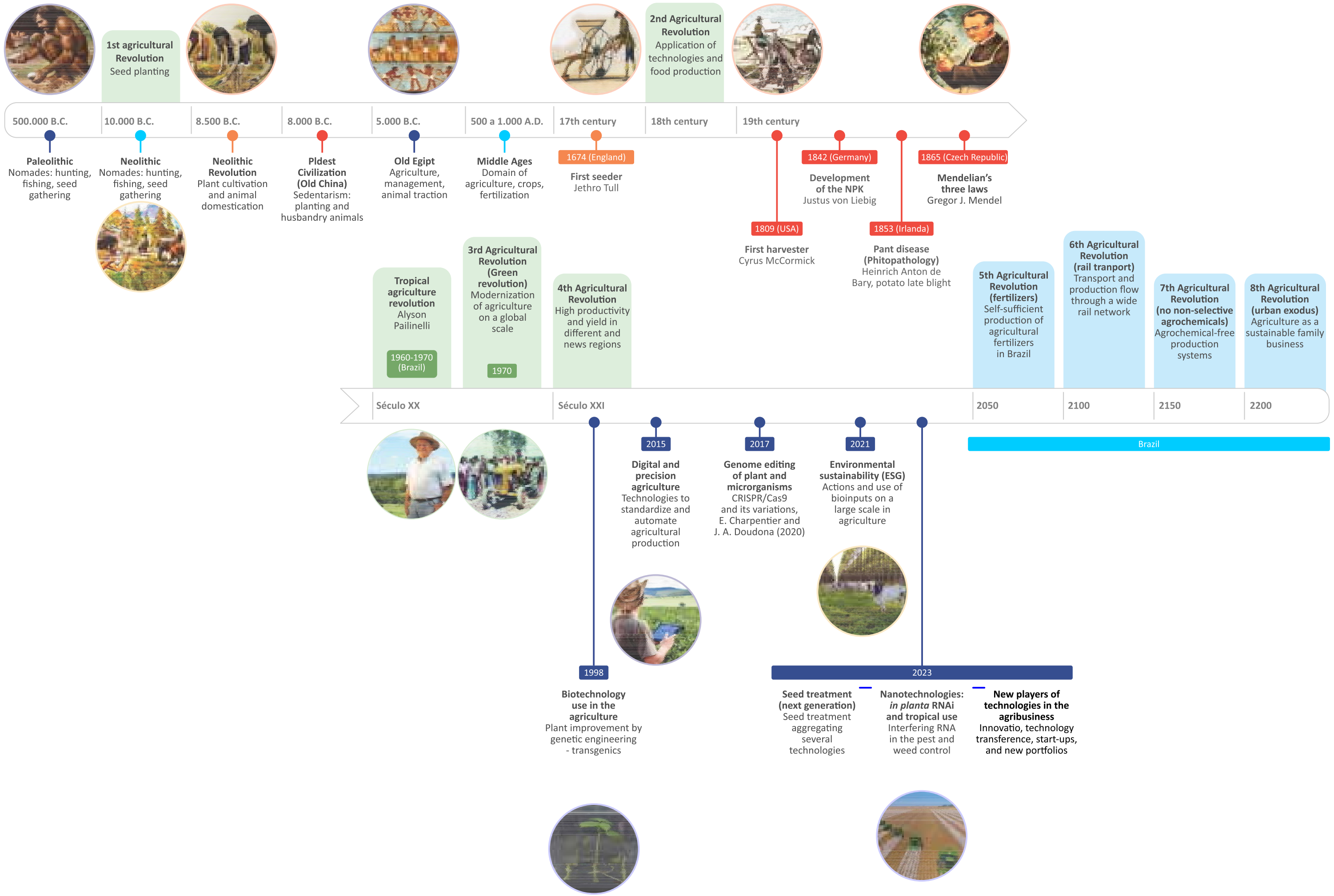
Humans emerged about 2.5 million years ago in East Africa. In the Paleolithic period (500,000 B.C.), they were characterized by nomadic life and fed essentially hunting, fishing and collecting plants, fruits and seeds. In the Neolithic period (10,000 B.C.), humans began to experiment with agriculture, although still living as nomads, considered that seed planting was a safe way to produce and harvest their food. It was from this planting initiative that **the 1st Agricultural Revolution** or **Neolithic Revolution occurred** (8,500 B.C.), which comes down to **the possibility of not only extracting, but also planting and raising animals for survival needs** (Fig. 1). Observing these possibilities of growing plants and raising animals, humans realized that sedentary and civilized life would be the most viable way in the face of this scenario.

The first civilizations were reported in Ancient China (8,000 B.C.), in the valleys of the Huang-Ho River (Yellow River) and the Yang-Tsé River (Blue River). However, it was in Ancient Egypt (5,000 B.C.), on the banks of the Nile River, that agriculture had its outstanding importance for the maintenance of civilizations. In addition to the floods of the Nile River, which were considered important for local agriculture, due to the land becoming more fertile and productive, animal traction became relevant to agriculture. However, it was in the Middle Ages (500 to 1,000 A.D.) that agriculture again had its importance highlighted as a result of its greater domain, by the use of soil management techniques and cultivation systems, although not yet having great technologies, a fact that characterized agriculture at the time as totally dependent on human and animal labor.

The first technological milestones in agriculture emerged in the 17th century, with the invention of the first mechanical seed planter by Jethro Tull, in 1701. This invention served as a reference and incentive for the development and application of new technologies in agriculture, aiming to reduce labor dependence and increase crop productivity and yield. The **use of these first technologies in agriculture marked the 2nd Agricultural Revolution**, which took place in the 17th century. Later, another technological milestone that marked agriculture in the 19th century was the invention of the first seed harvester by Cyrus McCormick, in 1809, indicating that, in addition to planting, the harvest could also be mechanized. Other factors, besides mechanization, began to prove important for the evolution of agriculture, such as soil fertilization. Although fertilization was highlighted in the Middle Ages by the use of organic waste, manure, carcasses and humus of rivers, the main milestone in soil fertilization was with the emergence of mineral nutrition from NPK (nitrogen, phosphorus, and potassium) in the 19th century, in the concept of Justus



Evolution of global agriculture and its techniques over the years to the present day, and optimistic forecasts for the next 200 years of Brazilian agriculture based on the demand and benefits for agribusiness that can be impactful for self-sufficient food production. The timeline presented highlights the main milestones of agriculture worldwide, with emphasis on technological advances achieved in recent years in Brazilian agriculture. Credits: photos retrieved from Google (original authors not mentioned). Abbreviations: B.C.: Before Christ; A.D.: Anno Domini.; NPK: Nitrogen, phosphorus and potassium macronutrients; CRISPR/Cas9, clustered regularly interspaced short palindromic responses-associated Cas9 endonuclease; ESG: Environmental, Social, and Governance.

von Liebig, in 1842, as a result of the fact that nutrition via organic waste was no longer enough.

Despite the momentary domain of planting, management, and harvesting technologies, it was also in the 19th century that Gregor J. Mendel, in 1865, demonstrated that it was possible to make targeted crosses between sexually compatible plants, indicating that characteristics of interest could be combined or transferred between different compatible species (Miko, 2008). Just before Mendel's three laws were validated, the occurrence of potato reburn disease in Ireland (1845 to 1850), which devastated potato cultivation and caused 2 million people to die of hunger and 1 million to emigrate, was characterized by Heinrich Anton de Bary, in 1853, as being caused not by abiotic conditions, but by phytopathogenic fungus *Phytophthora infestans* (Bourke, 1964).

These collective discoveries warned that agriculture had great potential for expansion and growth, but that it depended on constant technological and scientific evolution. This message brought good fruits, marked by advances highlighted, mainly, in tropical Brazilian agriculture, through the application of knowledge and concepts for a better exploitation of agriculture considering its specificities. The generation and application of scientific knowledge in agriculture marked the **Revolution of Sustainable Tropical Agriculture in the 20th century**, which had a great exponent in Brazil the agronomist Alysson Paulinelli. The agrarian sciences in Brazil led to revolutionary technologies, such as no-tillage, at least two crops a year, more efficient land use, complete fertilization, crop-livestock-forest integration, research centers focused on solutions for agriculture, among others, leading the country to self-sufficiency of food. This contributed to the **3rd Agricultural Revolution in the 20th century**, **marked by the modernization of agriculture on a global scale** (1960-1970), through **the use of technologies on the different fronts of agriculture.**

Soon after, with the important advance of genetic improvement in different crops and animals, domain of technologies and cultivation systems, **the 4th Agricultural Revolution occurred** (21st century), **marked by high productivity in different regions of the country, yield, quality of products, process traceability, use of artificial intelligence, bigdata, unmanned aircraft coupled to** cameras with RGB color system (red, green, and blue), thermal and multispectral for aerial images. This digital age in agriculture has been conceptualized as **precision and digital agriculture**, which has come to automate agricultural production and turn it into a more dynamic, friendly, and interconnected environment. Particularly, digital agriculture 4.0, which uses information technology, aggregates a large set of technological tools that collect, process, analyze, and store data from various operations, supporting the producer in decision-making in a more assertive way. Similarly, large-scale DNA sequencing techniques, using platforms that allow generating a large amount of data in a few hours or days at low cost, have enabled obtaining and using DNA level information from plants, animals, pathogens and microorganisms in general (Marks *et al.*, 2021).

More recently**, the use of plant biotechnology in agriculture** (soybean tolerant to glyphosate, 1998), via plant breeding by genetic engineering (transgenic), revealed that new technologies could be developed from the manipulation of the genetic material of a plant to meet the needs of agriculture, leading to the development of GMOs with several properties of interest for food production (Rolla *et al.*, 2014; Ribeiro *et al.*, 2017; Basso et *al.*, 2020). In addition to herbicide tolerance, other already commercial technologies that use transgenics were developed for resistance to pest insects through the expression of Cry and/or VIP proteins and for tolerance to water deficit through the expression of transcription factor HaHB4 (Ribichich *et al.*, 2020). As an example, there are no sources of varietal resistance or commercial cotton transgenic events to control the insect cotton boll weevil. However, several studies in progress at Embrapa Recursos Genéticos e Biotecnologia (Brasília, DF) seek the development of technologies for the control of this pest, through the expression of Cry toxins, or combining the expression of these proteins with the Interferent RNA (RNAi) technology, both already with good results observed with transgenic cotton lines evaluated in greenhouse (Ribeiro *et al.*, 2017; Ribeiro *et al.*, 2022; Vasquez *et al.*, 2023).

In parallel, with multidisciplinary technologies and their constant evolutions, CRISPR/Cas9 genome editing technology was established and applied in cultivated plants (Jinek *et al.*, 2012; Basso *et al.*, 2019). Genome editing technology, being simpler and more effective, has brought new alternatives for plant breeding through genetic engineering, which allows binding or disconnecting genes from the target cultivated plant itself, without the need to introduce a gene of another species, enabling superior plants with unprecedented agronomic characteristics and less time and cost of development (Basso *et al.*, 2020; Távora *et al.*, 2022). Genome editing allows the development of crops with greater resistance to abiotic stresses (lack or excess of rainfall, soil acidity) and biotic (pests), increased productivity, yield and quality (health and nutrition content). More specifically, the editing of genomes using the CRISPR/Cas9 technique allowed obtaining superior sugarcane plants with better digestibility of the cell wall by Embrapa Agroenergia (Brasilia, DF), soybean with greater tolerance to water stress by Embrapa Soja (Londrina, PR), soybean with higher productivity or without antinutritional factors by GM seeds (Londrina, PR). The negative post-transcriptional regulation via RNAi of the *AIP10* gene of soybean and cotton was shown to increase the precocity and yield of biomass, grains, and floral buds, and with genomic editing technology Embrapa Recursos Genéticos e Biotecnologia is seeking to develop plants with the *AIP10* gene turned off (Ferreira *et al.*, 2011; Hemerly *et al.*, 2022). In addition to plants, the editing of genomes of microorganisms beneficial to cultures has also been explored in order to obtain improvements in the interaction with plants (Yi *et al.*, 2018; Wang *et al.*, 2021).

It is also important to note that global climate change has been increasingly evident and intense, bringing negative impacts to agriculture. In view of this, **the balance and sustainability of ecosystems have gained more and more importance worldwide**. The recent emergence of the ESG (Environmental, Social, and Governance) concept organizes a new path based on environmental sustainability to be followed by global agriculture, as well as agribusiness in its entirety. These good business practices already reflect directly on the greater use of bio inputs (natural and biological products) in agriculture and the reduction of dependence on synthetic agrochemicals. The use of microorganisms that promote better growth and productivity of plants by increasing nutrient availability, such as N and P, and improving the rhizosphere is one of great relevance and leadership in Brazil (Meyer *et al.*, 2022). There is also the use of genetically improved plants (obtained by methods of transgenesis and/or genome editing) with improved relevant agronomic characteristics, and the use of antagonist microorganisms or that exert biological control of pathogens and pest insects are some examples of this new direction of agriculture (Costa *et al.*, 2019; Ribichich *et al.*, 2020; Meyer *et al.*, 2022).

It is noteworthy that Brazil has great potential to take the lead in sustainability in agribusiness. Estimates are that 30.2% of its territory for agriculture (8% native pastures, 13.2% planted pastures, 1.2% planted forests, 3.5% in infrastructures, and 7.8% for crops), while 66.3% correspond to areas destined for protected and preserved vegetation (16.5% native vegetation, 13.8% indigenous lands, 10.4% total conservation units and 25.6% preservation of rural vegetation) (IBGE, 2017). Another highlight is that Brazil was a pioneer in the exploitation of biofuels and today is among the two largest producers in the world, with emphasis on bioethanol produced from *sugarcane* and biodiesel from processed soy. In addition, Brazil has adopted the Low Carbon Agriculture Program (ABC Program), which integrates actions of federal, state and municipal governments, the productive sector and civil society to reduce greenhouse gas emissions from agricultural and livestock activities (MAPA, 2023). For example, the Soy Low Carbon Program, led by Embrapa Soja is creating a protocol to certify soybean-producing areas with low greenhouse gas emissions, which will enable the recognition of properties with sustainable production. Another important example, the National Institutes of Science and Technology (INCTs in Portuguese), financed by the Federal and State Governments, has been instrumental in articulating, aggregating, and boosting, at the national and international level, the best scientific and technological research groups in science frontier areas and strategic fields to contribute to the sustainable development of the country. In this same context, in 2023 Embrapa completed 50 years, being recognized for the decisive action for the development of Brazilian agribusiness through scientific research and development of solutions.

Combined with these recent advances aimed at the sustainability of agriculture, seed treatment aggregating several technologies, such as a mixture of biological inputs for pest and disease biocontrol, growth promotion, macro and micronutrients, elicitors (or inductor molecules) to enhance the immune system and the development and plant growth, it has contributed to the emergence of the new generation of seed treatment (Cardarelli *et al.*, 2022; Meyer *et al.*, 2022). In addition to the world of **new generation seeds, the use of nanotechnologies associated with RNAi technologies directly in plant genetics or topical use via the spraying of molecules, which will be active only in the target organism,** is revolutionizing agriculture (Ribeiro *et al.*, 2022; Tabora *et al.*, 2022; Vasquez *et al.*, 2023). Brazilian agriculture records annual losses greater than 15% due to pathogens (e.g. nematodes; Lopes-Caitar *et al.*, 2019), pest insects, e.g. cotton boll weevil (Oliveira *et al.*, 2012; IMEA, 2023), and weeds (Cruz *et al.*, 2020), which can be minimized by the use of these biotechnologies. Particularly in reference to nanotechnologies, the development of nanoparticles or carrier polymer nanostructures has revealed their potential for use in protection, better internalization, and greater effect of encapsulated biomolecules (DNA, RNA, proteins or elicitors) (Vasquez *et al.*, 2023). This new control strategy is based on biological inputs (nucleic acids of natural origin) that are not aggressive to the environment and act highly specific in the target organism, be it a phytopathogenic agent, pest insect, or weed.

All these new technologies and their evolutions have opened the opportunity for the emergence of new players of innovation, technology transfer, startups, and portfolios in agribusiness for the democratization of access to markets. The increase in the supply of innovative solutions, services, and disruptive technologies has contributed significantly to greater implementation and use of these assets in agriculture. The valorization by the agribusiness sector of technologies and assets generated by the Brazilian public or private initiative will be of great importance for a greater financial return of agriculture and strengthening of research and development in the country. Of course, **a greater incentive for basic scientific research, applied research, or the development of new products is of extreme relevance for the country to monitor emerging technologies and their implementation in agriculture**. **Likewise, greater financial support and opportunities for the education system of all levels of education are of extreme importance for the good training of human and professional resources in all areas, mainly focused on agribusiness**. In addition to this indispensable support to the teaching, research, and development sector, other sectors related to agribusiness need initiatives for its development. As an example, the fertilizer sector, which has been impacted by the Russia-Ukraine-US war (and the imminent China-Taiwan-US tension), and its consequences on foreign trade and public and private embargoes, has warned Brazilian agribusiness about the high risk of dependence on imports of fertilizers from countries in geopolitical conflicts. Due to that, the government's support for initiatives aimed at increasing local production and making Brazil less dependent on fertilizer imports is of extreme importance for agribusiness in the coming years. Brazilian self-sufficiency in fertilizers is predicted as one of the important milestones for the stability of a country in which agribusiness is the main activity that moves the economy, a factor that could mark the **5th Agricultural Revolution in Brazil**. This 5th Agricultural Revolution, as well as from **6th to 8th Agricultural Revolution** cited in sequence, are optimistic forecasts for the next 200 years of Brazilian agriculture based on the demand and benefits to agribusiness that can be impactful to the self-sufficient production of food. Likewise, more intense and effective efforts of the public initiative in the logistics sector for transport and disposal of agricultural production via development, expansion and improvements of the railway network, as well as the ports infrastructure, are important to improve the dynamics and reduce the costs of transporting agricultural products. Combined with this, investments for improvements in the infrastructure portion of agricultural products´ storage are necessary and may bring more stability to the sector. The implementation of a wide rail network that connects all Brazilian states and ports assertively and improvements in storage infrastructure will bring great transformations to agribusiness and may mean the 6th Agricultural Revolution in Brazil.

This new geopolitical reconfiguration and its impacts, combined with the effects of pandemics on human health (COVID-19, Monkeypox, etc) and animal health (African swine fever in China, avian influenza, mad cow disease), extreme weather events (frequent and intense droughts, off-season frosts, excessive rainfall, La Niña phenomenon), trade war (China, Russia, United States, European Union), political conflicts between democracies and autocracies, unprecedented private boycotts to conflict countries, consumer agglutination (social media, online and *offline* media, influencers, *e*-commerce, marketplace, censorship, fake news, activism for different causes), crisis in international logistics (strikes, maritime accidents, interruptions, geopolitical conflicts, high prices), large price fluctuations in general (supply and demand gaps, product shortages, inflation, currency volatility) and strengthening pest insects and diseases (increased production costs) reinforce the importance of immediate actions. These actions are critical to ensuring food safety in Brazil and worldwide. These actions also aim to improve the quality of life and the production of healthy food, preserving the environment, such as the long-term adoption of production systems without pesticides, or at least without synthetic or non-selective pesticides, that could result in the **7th Agricultural Revolution** in Brazil. All these disruptive technologies and advances in different segments of agribusiness can stimulate the return of part of the population from urban centers to the agricultural environment, resulting in what could be the **8th Agricultural Revolution in Brazil**, **marked by the urban exodus, which is the most important factor in the development of the agricultural sector, valorization of small producers, diversification of agriculture and use of agriculture as a sustainable family business and a healthier life**.

Finally, the constant generation of knowledge, technological innovation, the transfer of technology to agribusiness, dynamic communication, and sustainability of ecosystems will be decisive for global agriculture, for improving the quality of life of people in all social classes, and for food security. In this same sense, the strengthening of a long-term thinking mindset, with more investments in priority areas and exports of industrialized products, with higher added value and less raw material, will be important for the country's socioeconomic development. These initiatives can maintain Brazilian agribusiness among the four largest world powers in food production, or even increase this position, but with emphasis on environmental and social sustainability as a reference country.

Government initiatives of short, medium and long term, without politicization or harmful partisanization of agribusiness, and with the harmony of the public and private sector, between the urban and rural population are the path of the future that will enable the increase of production, ensuring food security with less cultivation area and invested resources. Only with investment in science will this be possible.