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Climate-Smart Agriculture for Achieving Food Security under the Modern Food Safety System: The Hazard Analysis and Critical Control Points (HACCP) System

Dr. Roukia Djerri

Faculty of Law, University of Constantine 1 Frères Mentouri Business Law – Competition and consumption

Laboratory of Contracts and Business, Faculty of Law, University of Constantine 1 Frères Mentouri

Email: roukia.djerri@umc.edu.dz

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Abstract:

Climate change, economic and political crises, and the spread of poverty and hunger worldwide have driven countries to reconsider their food production policies in order to ensure food security for their populations and, when possible, for the global community. Agricultural production, including both crops and livestock, remains the foundation of nutrition, food processing, and manufacturing. With the rapid pace of technological development, digital transformation, and the increasing reliance on advanced artificial intelligence systems, many countries have adopted climate-smart agriculture techniques to strengthen food security through innovative technologies. At the same time, legal frameworks are striving to keep pace with these fast-evolving transformations by establishing regulations that ensure effective oversight, safeguard food safety, and guarantee the provision of healthy and safe food. Among the most important systems for food safety control is the Hazard Analysis and Critical Control Points (HACCP) approach.

Keywords: Climate-smart agriculture, climate, food security, food safety, HACCP

Introduction

The world today is caught in a great struggle between climate change, the pursuit of food security, the need to keep pace with technological progress, the achievement of food safety, and the attainment of sustainability. It is a difficult equation that demands major efforts to strike the optimal balance amid the political, economic, social, cultural, climatic, and health transformations the world is undergoing, particularly in developing and poor countries. States must secure food for their populations, provided that they observe the required hygiene and sanitary conditions, especially under the modern global systems governing foods offered for human consumption.

Agricultural products form the foundation of the food supplied, whether consumed directly, prepared as meals, or used as raw or semi-processed material in the food industry.

Agriculture has not been spared by technological developments, artificial intelligence, and rapid digital transformation. These techniques are now widely used to obtain intensive agricultural yields in the shortest possible time, giving rise to what is known as climate-smart agriculture.

Faced with fierce competition among food-business operators in food markets, international and national legislation strives to adopt legislative and regulatory texts that keep pace with these developments. Modern ex-ante control systems have emerged for foods offered for human consumption, the most important of which is the HACCP system (the Hazard Analysis and Critical Control Points system), regarded as a self-regulatory, preventive control system.

The aim of this study is to examine climate-smart agriculture as a novel technique for achieving food security in the age of technological advancement and digital transformation. It also seeks to determine the extent to which this technique supports agricultural activity while ensuring food safety for individuals through modern legislation and modern food-control systems, particularly the HACCP system, and to identify the various advantages and disadvantages of the technique and of the means it employs.

On this basis, we pose the following research question:

Will climate-smart agriculture achieve its intended objective in light of the Hazard Analysis and Critical Control Points (HACCP) system, as a modern system for ensuring food safety?

To answer this question, we followed the plan below:

- **Part One – Climate-Smart Agriculture as a Technique for Achieving Food Security.**
- **Part Two – The Hazard Analysis and Critical Control Points (HACCP) System as a Modern System for Food Safety Control.**

Part One – Climate-Smart Agriculture as a Technique for Achieving Food Security

The use of modern information and communication technology, artificial intelligence, and digital transformation has reached every sector, including the food and nutrition sector, and especially the agricultural sector that is the subject of our study today in the form of climate-smart agriculture. This comes against the backdrop of climate changes that pose major challenges to the world in achieving food security, and after it has been established that conventional agriculture cannot cover the world's needs for agricultural products given the continuously growing global population. Accordingly, this part addresses the concept of climate-smart agriculture (First) and the modern technologies used in climate-smart agriculture (Second).

First – The Concept of Climate-Smart Agriculture

We address here the definition of climate-smart agriculture (I) and its objectives (II).

I. Definition of climate-smart agriculture: Several definitions of climate-smart agriculture have been offered, though they converge on a single meaning. It has been defined as an approach to developing agricultural strategies that ensure sustainable food security under climate change,[1] or as a set of agricultural practices designed to increase productivity, to improve and build the capacity to adapt to various shocks, and to mitigate the effects of climate change. It relies on three interrelated core criteria: sustainably improving agricultural production (productivity), enhancing resilience (adaptation), and reducing greenhouse gas emissions (mitigation).[2] It is also defined as a smart farming system that relies on advanced agricultural techniques to produce food in healthy ways, thereby preserving natural resources through the automation of agricultural operations such as irrigation, fertilization, pest control, and soil and crop monitoring, and through obtaining, analyzing, and managing accurate data,

[1]See the website: http://www.fao.org/climate-smart-agriculture/en (accessed 25 August 2025, 23:30).
[2]Girma Tilahun, Amare Bantider and Desalegn Yayeh, "Empirical and methodological foundations on the impact of climate-smart agriculture on food security studies: Review," *Heliyon* 11, no. 1 (2025): e41242, pp. 2–3.

which is sound guidance for making appropriate decisions in the agricultural production process.[3]

Climate-smart agriculture (CSA) is a modern technique that addresses the problem of food security and works on managing ecosystems and climate change. The idea originated in a report of the Food and Agriculture Organization (FAO),[4] which presented the first formulation of the concept of climate-smart agriculture under the title "Food Security and Climate Change Mitigation in Developing Countries: Options for Achieving Synergy." The report was launched in November 2009 at a workshop on climate change in Barcelona, and the concept was then confirmed at the 2010 Hague Conference on Agriculture and Food Security, titled "Climate-Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation."[5] The second international conference, held in Hanoi in 2012 on climate-smart agriculture policies, then established the methodology and principles of this modern technique, and since then interest in climate-smart agriculture has grown considerably.[6] It should be noted that climate-smart agriculture encompasses the four principal activities of agricultural production, namely crop production, livestock production, forestry, and fisheries and aquaculture, with each sector examining the effects of climate change and the climate-smart options available. These four activities give rise to what are known as integrated production systems within integrated agricultural production.[7] Climate-smart agriculture rests on three core pillars: food security, farmers' well-being, and adaptation to climate change and mitigation of its effects.[8]

II. Objectives of climate-smart agriculture: The overall objective of climate-smart agriculture is to support efforts at the local and global levels to use agricultural systems sustainably in order to achieve food and nutrition security for all people at all times. Sustainable increases in agricultural productivity support equitable increases in income and food security, as well as development, adaptation to climate change, and the building of resilience to it, from the farm level to the national level, while developing opportunities to reduce greenhouse gas

[3]Abeer Muhammad al-Balawna and Yahya Abu Sini, "The Concept of Smart Agriculture and the Jordanian Experience in Its Application," *Arab Scientific Journal for Youth*, no. 36, December 2021, p. 27.
[4]Asma Belhathat, "Climate-Smart Agriculture for Achieving Food Security in the Arab Countries," *Journal of the New Economy*, vol. 15, no. 1, January 2024, p. 249.
[5]Leslie Lipper et al., *Climate Smart Agriculture: Building Resilience to Climate Change* (FAO, 2018), p. 18.
[6]Latifa Bouklikha, "Climate-Smart Agriculture for Achieving Food Security in the Face of Climate Change Challenges: The Case of Algeria," *Al-Bashaer Economic Journal*, vol. 8, no. 3, December 2022, p. 435.
[7]*Climate-Smart Agriculture Guide: Summary of the Second Edition* (Rome: Food and Agriculture Organization of the United Nations, 2018), p. 5.
[8]See the website: https://open-library.cirad.fr/files/2/2400_ (accessed 13 September 2025, 15:27).

emissions relative to previous trends.[9] The work proceeds on the possibility of creating enormous synergy between climate change mitigation and sustainable agricultural development, especially for developing countries, and on building financing mechanisms to support it, as its importance grows with each passing day.[10]

Climate-smart agriculture also works to promote agricultural innovation and create green jobs while protecting the environment through better management of natural resources, increased production, and improved quality of agricultural crops. It applies sustainable natural resource management, with improved soil management and fertility, and converts animal waste into biogas as an alternative and renewable source of energy.[11]

Climate-smart agriculture also seeks to enhance biodiversity, efficiency, self-sufficiency, self-regulation, and self-reliance in agricultural systems by combining plants, livestock, and crops.

Improved management of pests and diseases, of water and nutrients, and of landscapes, rangelands, and forests constitute additional elements that can strengthen adaptive capacity and reduce the risk of food insecurity. The ultimate goal of climate-smart agriculture is sustainability, meaning that agricultural systems have the greatest possible resilience in the face of climate change while at the same time providing food security.[12]

Second – Modern Technologies Used in Climate-Smart Agriculture

Farming methods have evolved considerably, particularly on large farms, where traditional methods have been replaced by modern technological ones such as vertical farming, modern greenhouses, DNA technology, genetic modification, artificial (lab-grown) meat, three-dimensional printing technology, and so on. All of these require advanced technologies that use digital transformation, artificial intelligence, and the Internet of Things. Among the most important modern technologies used in climate-smart agriculture are: the Internet of Things (I), precision agriculture (II), artificial intelligence (III), unmanned aerial vehicles (drones) (IV),

[9]Leslie Lipper et al., "Climate-Smart Agriculture for Food Security," *Nature Climate Change* 4 (December 2014): 1069.
[10]Lipper et al., op. cit., pp. 22–24.
[11]Nabila Smar, "The Importance of Smart Agriculture and Food Industries in Achieving Food Security: The Kingdom of Bahrain, Saudi Arabia and the United Arab Emirates as Models," *Journal of Economic and Financial Research*, vol. 9, no. 1, June 2022, p. 443.
[12]Imaneh Goli et al., "Contributions of Climate Smart Agriculture Toward Climate Change Adaptation and Food Security: The Case of Mazandaran Province, Iran," *Trends in Food Science & Technology* (journal pre-proof), October 2024, pp. 4–5.

the application of monitoring and surveillance systems (V), nuclear techniques in climate-smart agriculture (VI), and remote sensing devices (VII).

I. The Internet of Things: The Internet of Things is the capability of connecting various devices and objects to the internet, and of enabling them to communicate with one another through the network and cloud services in order to exchange information, so that each component can perform its specific task and function.[13] It is a system designed to monitor agricultural fields with the help of sensors (sensors tracking light, humidity, soil acidity, weather, temperature, crop health, and so on), in addition to irrigation automation systems, allowing farmers to monitor their fields from anywhere and to choose between automatic and manual modes.[14]

II. Precision agriculture: Precision agriculture is a comprehensive concept for the Internet-of-Things-based approach that makes agriculture more controlled and precise. It is defined as "the approach used in managing farms and controlling crops through information and communication technologies, sensors, remote-control systems, and autonomous machinery, with the aim of obtaining precise data and using it to steer farming precisely toward better production, of high quality, and at lower cost."[15] This type of agriculture has existed for a long time, but its application was impossible for several reasons, chief among them the gap between food supply and demand and the shrinking of arable land. It focuses on the efficient use of natural resources and the protection of the natural environment. There are four steps for its application: determining the extent and scope of variability in soil and crop characteristics; interpreting the significance and causes of that variability; managing the variability on a spatial and temporal basis; and monitoring the results produced by variability-management practices.[16]

III. Artificial intelligence: Under climate-smart agriculture, artificial intelligence is now used on a wide scale, providing farmers with services for precise data analysis, imagery, reports, and

[13]Salma Saadaoui and Mounir Kharouf, "The Internet of Things: Smart Agriculture as a Mechanism for Achieving Economic Diversification, with Reference to Leading International Experiences," see the website: https://www.researchgate.net/publication (accessed 18 September 2025, 10:40).
[14]"How Will Internet of Things Technology Change the Future of the Agricultural Sector and Global Food Supply Chains," Islamic Transactions Fiqh Research Center, see the website: https://kantakji.com/5777/ (accessed 18 September 2025, 10:57).
[15]Nesrine Mokaddem and Tarek Fares, "The Trend toward Smart Agriculture to Achieve Food Security in the Arab Countries, with Reference to Successful Arab Experiences," *Journal of Economics and International Trade*, vol. 5, no. 1, December 2023, p. 64.
[16]Taimoor Qureshi et al., "Smart Agriculture for Sustainable Food Security Using Internet of Things (IoT)," *Wireless Communications and Mobile Computing*, vol. 2022, Article ID 9608394, 2022, p. 4.

comparison across fields.[17] Artificial intelligence also enables farm management through predictive analytics of the various data relating to agriculture and crop production across all stages, so that appropriate decisions can be made to achieve productive returns.[18] In addition, robots are used in agriculture; robotic farming is highly precise and fast, handles produce more gently than workers, and costs less.[19] Artificial intelligence has been applied in machinery and in biotechnological information.

IV. Unmanned aerial vehicles (drones): The beneficial uses of this technology are most apparent in its application to the agricultural field, where it enables remote crop monitoring, soil analysis and fertility improvement, improved efficiency in the use of water and fertilizers, and early detection of pests and diseases,[20] as well as preventing human exposure to them, through the use of remote sensing in agriculture, which makes it possible to collect precise data on the condition of crops and soil and allows farmers to take proactive measures to improve production.[21] Drone technology has attracted wide attention in this field owing to its versatility and its being regarded as the future of the farming community; it is an integral part of precision agriculture, in addition to its contribution to sustainable agriculture.[22]

V. Application of monitoring and surveillance systems: Regular project monitoring involves collecting data on the progress of activities and outputs and on financial management, and flagging emerging problems or good practices. This relies on management information systems, which are web-based support systems increasingly managed through remote devices and linked to financial management systems and geographic information systems.[23] Monitoring systems can be applied, especially by owners of large farms, by using the Internet of Things to collect data on the location, well-being, and health of their livestock, to identify sick animals so as to separate them from the herd, and to determine calving dates so as to take the necessary

[17]Muhammad Lakhal, "Economy, Health and Agriculture in the Age of Artificial Intelligence," *Journal of the Institute of Economic Sciences*, vol. 26, no. 2, 2023, p. 36.
[18]See the website: https://www.itu.int/en/mediacentre/backgrounders/Pages/artificial-intelligence-for-good.aspx (accessed 18 September 2025, 12:09).
[19]Mokaddem and Fares, op. cit., p. 66.
[20]Mohammad Vaheed and Ashish Kumar Verma, "Drone Technology for Smart Agriculture," 1st ed., in *Emerging Trends in Biosciences* (InfoCapsule LLP, Lucknow, Uttar Pradesh, India, August 2023), pp. 103–128, at pp. 107–109.
[21]See the website: https://farmonaut.com/precision-farming (accessed 18 September 2025, 13:00).
[22]Gunawan S. Prabowo et al., "Drone-assisted climate-smart agriculture (DACSA): A spatially-based outcome prediction model as an initial approach to track yield changes in shallot planting areas," *Kuwait Journal of Science* 52, no. 2 (April 2025): 7.
[23]Ibsa Dawid Mume, "Assessment, Monitoring and Evaluation of Climate Smart Agriculture: A Review," *International Journal of Food Science and Agriculture* 5, no. 3 (September 2021): 514.

measures; they also allow farmers to reduce labor costs.[24] Monitoring and surveillance systems are numerous, the most important being satellite imagery, the Internet of Things, digital security, and pest and insect control (AI companies help send alerts to farmers on their smartphones about insects and various pests that may affect their crops and agricultural products so that they can take appropriate precautions), as well as monitoring soil and crop health, which determines the type and location of pesticide spraying.[25] Monitoring and surveillance systems are regarded as part of good agricultural and health practices. They are ex-ante control systems based essentially on food safety standards that rest on the same principle, foremost among them the Hazard Analysis and Critical Control Points (HACCP) system, an ex-ante self-monitoring system applied by food establishments, in which the hazard is detected and eliminated before it occurs.

VI. Nuclear techniques in climate-smart agriculture: Nuclear and related techniques can enhance agriculture's resilience to climate change, reduce greenhouse gas emissions, increase agricultural productivity, and produce and improve the performance of many climate-resilient crop varieties. Nuclear techniques can also be used to monitor agrochemical inputs and to manage water by tracing water movement and pathways and developing technology packages that save water.[26] However, this technique faces many challenges, including problems of practical conception, high initial costs, regulatory concerns, environmental impacts, and a lack of awareness and training among farmers,[27] especially in developing countries.

VII. Remote sensing devices: Remote sensing is a geospatial technology used in agriculture to monitor crop health and nutrient concentrations and for early disease detection.[28] It is also used to track climate, particularly changing weather conditions such as humidity, rainfall, and temperature, and to detect dew in order to choose suitable crops to plant; and to analyze soil quality by choosing the type of fertilizers, identifying dry parts of the field, analyzing the soil's drainage capacity, adjusting irrigation water levels, and choosing the optimal species to

[24]Mokaddem and Fares, op. cit., p. 65.
[25]Nawara Siyari and Houda Jebli, "Smart Agriculture: The Wager of the Future toward Developing Agriculture and Strengthening Food Security – Challenges and Prospects," *Al-Basaer Journal*, vol. 2, no. 1, June 2023, pp. 33–34.
[26]Julius Cesar Trajano, "Expanding the Peaceful Uses of Nuclear Technology and Climate Change Adaptation: Opportunities and Challenges," RSIS, Nanyang Technological University, Singapore, *NTS Insight*, no. IN22-04, August 2022, p. 3.
[27]Arham Tater et al., "A Leap Forward: Use of Nuclear Technology in Agriculture," *The Agriculture Magazine*, vol. 4, issue 5, January 2025, p. 596.
[28]Muhammad Zakwan Hadeed et al., "Role of Remote Sensing and GIS for Sustainable Crop Production under Climate Change," in *Advancements in Climate and Smart Environment Technology*, May 2024, p. 154.

cultivate.[29] Remote sensing technology uses devices that collect data across multiple wavelengths of light.[30]

Part Two – The Hazard Analysis and Critical Control Points (HACCP) System as a Modern System for Food Safety Control

The Hazard Analysis and Critical Control Points (HACCP) system is regarded as one of the modern, integrated control systems, approved and recognized by specialized international bodies and organizations. Indeed, it has become one of the requirements by which the quality of a food establishment is judged. Accordingly, we address what the HACCP system is (First) and the rules for applying the HACCP system (Second).

First – What the HACCP System Is

We address here the definition of the HACCP system (I), its benefits and requirements (II), and the procedures for applying it (III).

I. Definition of the HACCP system: HACCP is a system concerned with the health and safety of food products. It works to identify, assess, and control potential hazards, whether microbial, chemical, or physical, at all stages of the food chain, from the farm through handling, preparation, processing, and manufacturing to arrival at the consumer.[31]

It can also be defined as a system that provides entry into the international trade market and success in exporting. It is a regulatory food-safety program that identifies points of hazard in the food production and manufacturing chain through what are known as critical points, and monitors these points in order to control them and prevent hazards. It is a regulatory approach that aims to protect human health by ensuring food safety against biological, chemical, and physical hazards, and to secure a reputation for quality and recognition from competent governmental bodies and international organizations.[32] It is a method that relies chiefly on preventive measures during processing or serving rather than on testing the final product, and it is a system that can be developed and adapted to any change, whether in equipment, design, manufacturing steps, or technological developments.[33] Earlier traditional methods relied on

[29]Siyari and Jebli, op. cit., p. 40.
[30]Hadeed et al., op. cit., p. 154.
[31]Tamadur Kurdi, "The Hazard Analysis and Critical Control Points System," in *The Arab Encyclopedia of Food and Nutrition*, 1st ed. (Beirut: Academia International, 2009), p. 177.
[32]Sayyid Abd al-Nabi Muhammad, *The Modern Food Safety System HACCP* (Egypt: Arab Press Agency, 2019), p. 21. See also: Al-Rashid Ahmad Salim Khayr Allah, *Food Processing Quality and Safety: Highlights on Total Quality Management and HACCP*, 1st ed. (Sudan: National Library, 2014), p. 3.
[33]Iltizam Foundation for Ethical Standards, *The Commitment of the Food Establishment*, Series of Ethical Standards for Professions (Beirut, Lebanon: Dar al-Kutub al-Ilmiyya, 2010), pp. 88–89.

inspecting the food product at the final stage, which meant that, if it was contaminated, the product was discarded, costing the food establishment enormous sums. By contrast, the HACCP system works to identify the stage that led to the contamination of the food and to correct it.[34]

The HACCP safety standard was first published in 1992 and was adopted by the Codex Alimentarius Commission.[35] The World Health Organization emphasized the importance of its application, and, to ensure consumer safety, applying the system has become mandatory for exporters in some European and American countries.[36] In 1997, the Codex Alimentarius Commission incorporated the HACCP system into an annex to the General Principles of Food Hygiene and regarded it as one of the recommended international codes of good practice.[37] In the 1990s, many countries, notably Australia, Denmark, Germany, India, Ireland, the Netherlands, the United States, and others, adopted HACCP in national standards specifying the requirements of a food safety management system; the system was also incorporated into the European Community regulations on food hygiene. In 2005, the International Organization for Standardization (ISO) prepared the international standard ISO 22000:2005 for food safety management systems, setting out the requirements for any organization in the food chain, and this standard includes the HACCP system.[38]

Algeria, like other Arab and developing countries, has not issued legislative texts expressly requiring the application of the HACCP system. In 2017, Executive Decree No. 17-140 was issued, setting the hygiene and sanitary conditions during the placing of foodstuffs on the market for human consumption,[39] and regulatory texts implementing that decree were issued in 2021.[40] These texts provide for compliance with the hygiene and sanitary conditions of food offered for human consumption in accordance with the HACCP system.

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[34]Kurdi, op. cit., p. 177.
[35]Al-Hadi Muhammad Qunbayj and Fatima Ammar al-Hadi al-Aqabi, "The Importance of Applying Food Quality and Safety Management Systems in Food Industry Companies (A Field Study of Some Companies in the Arab Region)," *Journal of Applied Sciences*, first special issue, June 2019, p. 123.
[36]Kurdi, op. cit., p. 177.
[37]International Trade Centre (ITC), *Export Quality Management: A Guide for Small and Medium-Sized Exporters*, 2nd ed. (Geneva: joint agency of the World Trade Organization and the United Nations, 2011), p. 130.
[38]ITC, *Export Quality Management*, op. cit., p. 131.
[39]Executive Decree No. 17-140 of 11 April 2017 setting the hygiene and sanitary conditions during the placing of foodstuffs on the market for human consumption, Official Journal No. 24, issued 16 April 2017.
[40]Joint Ministerial Order of 1 December 2020 setting the conditions and modalities for applying the hazard analysis and critical control points system, Official Journal No. 07, issued 31 January 2021. And the Joint Ministerial Order of 1 December 2020 setting the conditions and modalities for approving guides of good hygiene practices and applying the principles of the hazard analysis and critical control points (HACCP) system, Official Journal No. 07, issued 31 January 2021.

II. Benefits and requirements of the HACCP system: We address the benefits of the HACCP system (1) and its requirements (2).

1. Benefits of the HACCP system: Among the most important benefits of the HACCP system is that it:

- is a scientific and systematic approach to identifying and controlling hazards during the production, processing, preparation, and distribution of food. It is also used in education, since it entails knowing the practices followed in food preparation and identifying those that lead to food contamination, and it helps trace foodborne illnesses by helping to identify the cause of an outbreak.
- can be applied along the entire food chain, from the production of raw materials to the food's arrival at the consumer, including the stages of farming, harvesting, transport, storage, processing, distribution, and consumption.[41]
- allows food-control resources to be concentrated where they are most likely to have the greatest impact on the public. It is therefore in governments' interest to base their decisions on the principles of risk analysis, and transparency must be the rule when communicating about risks with the various stakeholders; the system's principles also allow control resources to be focused on the foods likely to have the greatest impact on the public.[42]
- can be applied in all food establishments, small and large alike, and helps in identifying and controlling the stages of food preparation instead of discarding the product when a defect appears in the final product.[43]
- follows a preventive-planning approach to confirm product safety and quality; offers an ideal model for effective control of food-borne hazards; makes it possible to know the sources of hazards at the various stages of production, including potential ones; rationalizes spending on the critical points in the production and manufacturing process;

[41]Kurdi, op. cit., p. 178.
[42]FAO and WHO, *Food Control System Assessment Tool – Section A: Inputs and Resources*, Food Safety and Quality Series (Rome, 2020), p. 29.
[43]Amir Abd al-Rahman al-Shaykh Zahir, *Food Hygiene – Theoretical Part* (Baghdad, Iraq: Dar al-Murtada, 2018); and Ali Kamil al-Sa'd, *Food Quality Control* (Jordan: Dar al-Maktaba al-Wataniyya, 2000), p. 120.

and reduces product loss,[44] while giving food establishments a greater chance of success as exporters in those countries.[45]

The advantages and benefits of the HACCP system also include the following:[46]

- It is a preventive system that makes the food establishment itself responsible for food control (self-monitoring), reduces the likelihood of product recalls, and reduces the number of inspection visits and inspectors from regulatory bodies. This eases the inspection task for the regulators and enables them to concentrate their objectives and efforts during monitoring on hazards that pose a severe threat to public health, making it easy to classify establishments according to their hygiene level. It also makes food handlers more understanding of food safety and ensures their effectiveness in producing safe food. Applying HACCP is a program that complements other quality management systems and facilitates joining quality systems such as the Total Quality Management system.
- It documents, in written form or by any other means that can be consulted when needed, everything affecting food safety.
- Applying the HACCP system raises the morale and efficiency of factory owners and workers, as a result of the product's quality and efficiency and the increased demand for it, and it heightens their sense of responsibility toward food safety.
- Applying the HACCP system encourages the development of food legislation and compliance with international legislation and guidelines, especially modern food safety systems such as microbiological risk assessment and food safety objectives, and strengthens international communication about microbiological hazards.

2. Requirements of the HACCP system: In hazard analysis and the subsequent processes of designing and implementing HACCP systems, importance must be given to the impact of raw materials and ingredients, food manufacturing practices, the role of manufacturing processes in controlling hazards, the end use of the product, the number of consumers who would be at risk, and the epidemiological evidence relevant to food safety.[47] To achieve this, a logical sequence

[44]*Food Control – Theoretical*, General Administration for Curriculum Design and Development, General Organization for Technical and Vocational Training, Kingdom of Saudi Arabia, 2008, p. 87.
[45]ITC, *Export Quality Management*, op. cit., p. 131.
[46]*The HACCP System*, Food Production ("Culinary Arts") specialization, 253 Chef, General Administration for Curriculum Design and Development, General Organization for Technical and Vocational Training, Kingdom of Saudi Arabia, 2008, p. 12.
[47]Al-Sa'd, op. cit., p. 584.

for implementing the HACCP system must be followed, consisting of: assembling or selecting the HACCP team;[48] describing the product;[49] identifying its intended use;[50] constructing a flow diagram of the manufacturing process;[51] and on-site verification of the flow diagram of the manufacturing process.[52]

Thus, given the objectives and requirements of the HACCP system as a food safety system, it is highly compatible with the climate-smart agriculture system and the mechanisms and techniques it adopts. The latter relies on the technique of monitoring and surveillance of agricultural products, whether crops or farm produce, so that the hazard is detected before it occurs, using modern technological techniques based on digital transformation. This is the same principle on which the HACCP system relies, since it detects the hazard before it occurs. This shows that good agricultural practices and good hygiene depend to a large extent on the HACCP system and vice versa. To build the HACCP system on a firm foundation of a food-hygiene program, attention must be paid to the prerequisite requirements, which include good manufacturing practices and good hygiene practices throughout all stages of the food chain.

III. Procedures for applying the HACCP system: Before a hazard analysis and critical control points system is developed, the food-industry establishment, its buildings, facilities, and equipment must be designed in line with the basic principles of hygiene; maintenance, cleaning, and pest-control equipment and waste-treatment procedures must also be available, and good practices regarding the health and cleanliness of employees must be applied.[53] All of this falls within good manufacturing and production practices and good hygiene practices, as well as the application of quality-control and total-quality programs.[54] The HACCP system is applied in factories and food establishments that are still in the planning and design phases of production, and to products that are at the development and modification stages.[55] The HACCP team must

[48]Kurdi, op. cit., p. 180. See also: *Application of the Hazard Analysis and Critical Control Points (HACCP) System for Food Handlers in Food Establishments*, Food Department, General Directorate of Environmental Health, Deputy Ministry for Municipal Affairs, Ministry of Municipal and Rural Affairs, Kingdom of Saudi Arabia, 2010, p. 13.
[49]Zahir, op. cit., p. 126. See also: ITC, *Export Quality Management*, op. cit., p. 133; and *BRC Global Standard for Food Safety*, Issue 8, August 2018.
[50]Kurdi, op. cit., p. 180. See also: *Application of the HACCP System for Food Handlers in Food Establishments*, op. cit., p. 14.
[51]*The HACCP System*, Food Production specialization, op. cit., p. 31. See also: Abd al-Nabi Muhammad, *The Modern Food Safety System HACCP*, op. cit., p. 159; and Zahir, op. cit., p. 127.
[52]See the annex to the Joint Ministerial Order of 1 December 2020 setting the conditions and modalities for applying the hazard analysis and critical control points system, op. cit.
[53]ITC, *Export Quality Management*, op. cit., p. 133.
[54]Al-Rashid Ahmad Salim Khayr Allah, op. cit., p. 64.
[55]*The HACCP System*, Food Production specialization, op. cit., pp. 4–5.

record all hazards associated with each step in the list, taking into account any preventive measures to control them. It must draw up a list of all biological, chemical, and physical hazards that may reasonably be expected to occur at each step and set out the preventive measures that can be used to control these hazards; the HACCP team then analyzes each hazard.[56] All information used during the hazard analysis is reviewed, and the plan is amended whenever necessary; it must also be amended when new information on potential hazards or concerns becomes available.[57]

Establishments subject to the HACCP system must also apply permanent procedures based on the principles of the HACCP system in order to ensure the safety and security of foodstuffs.[58] They must also establish and implement a traceability system that makes it possible to identify product batches and their relationship to batches of raw materials, together with records of production and delivery. The system must also make it possible to identify the direct suppliers of inputs and the direct customers of final products, facilitate control and the withdrawal of non-conforming foodstuffs, inform consumers, and determine responsibilities,[59] and the personnel responsible for applying the HACCP system must be given appropriate training.[60]

The hazard analysis system is an essential part of national food safety legislation, regulations, and programs, and all parties concerned with food safety, whether governmental bodies or private-sector entities, must be involved in adopting this system in their food establishments.[61]

Second – Rules for Applying the HACCP System

To implement the HACCP program, the HACCP team follows the seven principles of the system, namely: hazard analysis (I); determining critical control points (II); establishing critical limits (III); establishing monitoring and tracking procedures (IV); establishing corrective actions (V); establishing verification procedures (VI); and documentation (VII).

I. Hazard analysis: At this stage the food safety team (or HACCP team) must analyze the sources of hazard,[62] identify them, estimate their severity, and determine the preventive

[56]Al-Sa'd, op. cit., p. 588.
[57]Abd al-Nabi Muhammad, op. cit., p. 164.
[58]See Article 4 of the Joint Ministerial Order of 1 December 2020, cited above.
[59]See Article 7 of the Joint Ministerial Order of 1 December 2020, cited above.
[60]See Article 8 of the Joint Ministerial Order of 1 December 2020, cited above.
[61]Kurdi, op. cit., p. 177.
[62]*Application of the Food Safety Management System in Food Establishments*, op. cit., p. 48.

measures,[63] for every stage of the process flow diagram. The team also conducts a hazard analysis to identify the hazards that, by their nature, must be eliminated or reduced to an acceptable level, taking into account the causes of the hazards and the seriousness of their health consequences; the measures to be applied to control each hazard must also be determined.[64]

II. Determining critical control points: Here the critical control points are determined, namely those at which the identified hazards can be controlled,[65] or at which the hazard can be reduced to an acceptable level. A safety control is thereby established; where no such control exists, the product or the process must be modified at that step, or at an earlier one, in order to put a control in place.[66] A decision tree can also be applied[67] at each step (for each hazard); the steps at which monitoring is performed are called critical control points.[68] Loss of control over the process of identifying the critical points to be controlled will lead to unacceptable risks to consumer health.

III. Establishing critical limits: Critical limits are the values that must be achieved for each control measure associated with a critical control point, and they are used to distinguish between safe and unsafe manufacturing processes, or between safe and unsafe food.[69] The maximum or minimum value to which a physical, biological, or chemical hazard must be controlled at a critical control point is set so as to prevent, eliminate, or reduce that hazard to an acceptable level.[70] Critical limits are thus the control criterion that must be met in order to ensure a safe product.[71]

IV. Establishing monitoring and tracking procedures: This is also known as establishing systems for monitoring, observing, and measuring critical control points. It consists of microbiological, chemical, or physical tests or measurements carried out periodically, through which the degree of control over the critical points can be determined, using rapid and accurate tests that enable quick decision-making.[72]

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[63]*The HACCP System*, Food Production specialization, op. cit., p. 12.
[64]See the annex to the Joint Ministerial Order of 1 December 2020, cited above.
[65]Zahir, op. cit., p. 130.
[66]*BRC Global Standard for Food Safety*, op. cit., p. 15.
[67]A decision tree is defined as a sequence of questions applied at each production step with a known hazard in order to determine which production steps are critical control points. See: Zahir, op. cit., p. 122.
[68]ITC, *Export Quality Management*, op. cit., p. 134.
[69]Al-Rashid Ahmad Salim Khayr Allah, op. cit., p. 104.
[70]Saddam Hussein Mahdi al-Jubouri, op. cit., p. 14.
[71]Ashraf Muhammad Abd al-Malik, "The Modern Food Safety System," *Assiut Journal of Environmental Studies* (Egypt), no. 32, January 2008, p. 51. The Algerian legislator took the same approach and specified it in the annex to the Joint Ministerial Order of 1 December 2020, cited above.
[72]*Application of the Hazard Analysis and Critical Control Points (HACCP) System for Food Handlers in Food Establishments*, op. cit., p. 30.

A monitoring mechanism specific to each critical control point must be established to verify compliance with the critical limits; it must be capable of detecting loss of control at critical control points and of providing, in a timely manner where possible, the information necessary to take the required corrective action.[73]

V. Establishing corrective actions: These are the actions to be taken when the monitoring systems for critical control points show that a point is out of control and outside the critical limits.[74] They must include the measures that designated personnel are to take in respect of any products manufactured during the period of loss of control.[75] The corrective actions for each critical control point must ensure that the critical control point is brought back under control, must include the disposition of the non-conforming product, and the actions taken must be documented in the HACCP records.[76]

VI. Establishing verification procedures: These are the procedures by which the validity of the HACCP plan is determined and by which it is confirmed that the system is operating in accordance with the plan. The verification system must include internal and external audits, microbiological tests monitored at critical control points, customer visits and opinion surveys, and customer complaints.[77]

Monitoring and auditing methods, procedures, and tests are used, along with random sampling for analysis, to determine whether the HACCP system is working properly.[78]

VII. Documentation: Documentation relies on a continuous system of records, serving as a document and exhibit to demonstrate conclusively that the system operates effectively to ensure product safety.[79] At least four types of records are retained: the HACCP plan and all the information used in drawing it up, monitoring records, corrective-action records, and verification records.[80] These records and files must be simple and easy to use, with all documents archived and made available for inspection by the authorities.[81]

[73] *BRC Global Standard for Food Safety*, op. cit., p. 16.
[74] Al-Rashid Ahmad Salim Khayr Allah, op. cit., p. 107.
[75] *BRC Global Standard for Food Safety*, op. cit., p. 16.
[76] See the annex to the Joint Ministerial Order of 1 December 2020, cited above.
[77] Al-Rashid Ahmad Salim Khayr Allah, op. cit., p. 109. See also: Al-Sa'd, op. cit., p. 596.
[78] Al-Sa'd, ibid., p. 596.
[79] Kurdi, op. cit., p. 188.
[80] Abd al-Nabi Muhammad, op. cit., pp. 166–167.
[81] See the annex to the Joint Ministerial Order of 1 December 2020, cited above.

Thus, through the sequential stages of the HACCP system, it works as an integrated system for the monitoring and surveillance used in climate-smart agriculture technology, in that it detects the hazard, controls it, and eliminates it before it arises in the agricultural product, whether crops or livestock, whatever the nature of the hazard, in particular diseases, pests, and the levels of additives and chemicals carried by agricultural products.

Conclusion

Keeping pace with technological progress and digital transformation compels states to apply them across all the strategic sectors on which their economies and the lives of their people rest. The agricultural sector is among the most important strategic sectors that must receive attention in order to achieve food security and sustainable development and to preserve resources, in light of the negative changes the world is witnessing, particularly climate change. Accordingly, the techniques used in agricultural activity have been modernized in line with modern technological developments and contemporary digital transformation, and states have come to strive to move forward in developing and expanding climate-smart agriculture, as a technique that relies on modern and advanced technological mechanisms. At the same time, they take into account the guarantee of food safety through the application of modern control systems, the most important of which is the HACCP system.

In this study we therefore addressed climate-smart agriculture: its concept, its intended objectives, and its contribution to achieving food security, together with the modern technological techniques used in it. However, achieving food security alone is not sufficient to protect people's lives; this food must also ensure their safety through respect for the hygiene and sanitary conditions of the food provided to them. To achieve this, food establishments must apply ex-ante self-monitoring to the food products they produce before placing them on the market for consumption. This led us to address the HACCP system as a modern system consistent with the technological developments relied upon in food production and processing, and to examine the concept of the system, its associated benefits, the requirements and procedures for its application, and the rules followed in it. We reached a set of findings, the most important of which are:

1. Smart agriculture that uses innovative technologies such as artificial intelligence and the Internet of Things significantly improves traditional farming practices and facilitates precise monitoring of crops and environmental conditions, which inevitably improves agricultural productivity and ensures the achievement of food security.

2. Climate-smart agriculture relies on advanced technological techniques, which requires coordination between the agriculture sector and the Ministry of Higher Education and Scientific Research in order to implement it properly. The qualifications and competencies needed to implement it on the ground are very scarce, especially in developing countries.

3. There is complementarity and a reciprocal relationship between climate-smart agriculture and the Hazard Analysis and Critical Control Points system, as both are based on good agricultural and hygiene practices and on ex-ante self-monitoring and surveillance by food establishments, especially agricultural ones, since these are the foundation of nutrition, production, and food processing.

4. In light of technological developments and digital transformation, and their exploitation in providing food and achieving food security, legislation seeks to establish a set of legal texts and provisions compatible with this development, in order to control the supervision of the safety of foods intended for human consumption.

We also reached a set of recommendations, the most important of which are:

1. Encouraging the expansion of climate-smart agriculture, provided that the hygiene and sanitary conditions of food offered for human consumption are observed, since achieving food security alone is insufficient to guarantee people's health and lives.

2. States should mobilize all resources to make this precise technique succeed. This can be achieved only through joint collective action among the various sectors of the same state and between the public and private sectors, and through cooperation among the states seeking to apply climate-smart agriculture and the exchange of expertise, together with the provision of the necessary financial resources and infrastructure. Governments and the private sector should provide incentives or financial support for farmers, especially in developing regions.

3. Relying on start-up projects whose qualification begins at the university stage, and creating small enterprises that pursue projects with two aims, achieving food security and ensuring food safety; beginning to qualify young people for these advanced agricultural activities, especially during their academic training; relying on university laboratories in this field; and encouraging innovation and participatory research in order to achieve food security and safety together, while creating workshops and training courses online or in local and even international training centers.

4. Sustainability will not be achieved if one sector is neglected for the success of another: the success of agriculture in achieving food security can be achieved only by achieving the health and food safety of individuals. Sustainable and healthy agricultural practices must be adopted alongside technological developments, with effective policies and regulations that protect farmers' data privacy, ensure the ethical use of data, provide guidance for adopting smart agriculture, and address data-security concerns.

5. Legislative and legal efforts to establish a robust legal framework that regulates agricultural practices in line with technological developments and digital transformation in this field, in order to ensure the safety of agricultural products for human consumption, while establishing a legal framework for the governance of ethical principles and laying down clear and transparent rules.

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