Adam E. Ahmed
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Food and Nutrition Security in the Kingdom of Saudi Arabia, Vol. 1

National Analysis of Agricultural and Food Security

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Foreword

Achieving food security is of great concern to various nations worldwide as it plays a vital role in improving overall health, attaining economic and social stability, ensuring environmental sustainability, and upholding human rights by ensuring access to sufficient and safe nutritious food. The Kingdom of Saudi Arabia has significantly emphasized food security in the ambitious 2030 vision plan which includes various strategies intended to increase local food production, minimize food loss and waste, optimize water usage, promote agricultural investments abroad, support food processing and manufacturing, encourage international collaboration, and improve trade conditions for food products to ultimately achieve sustainable food security.

King Faisal University plays a significant role in ensuring food security in Saudi Arabia through research, education, and community outreach initiatives. Moreover, the university has centered its institutional identity around "Food Security and Environmental Sustainability" and actively supports research projects related to food security. In the context of achieving food and nutrition security amid critical issues such as population growth, high dependency on food imports, water scarcity, and climate change, this timely book provides a comprehensive analysis of the challenges faced in Saudi in achieving food security. It covers a wide range of topics and examines the roles of different sectors in contributing to food security. One of its strengths is its multidisciplinary approach, which aligns with the nature of food security and aims to develop sustainable solutions. The book is a valuable resource for policymakers, researchers, and students interested in understanding the challenges and opportunities related to food and nutrition security in Saudi Arabia.

The editors of this book are proudly affiliated with the College of Agricultural and Food Sciences at King Faisal University. Dr. Adam E. Ahmed is the founder of the Albilad Bank Chair for Food Security as well as the Food Loss and Waste Research Chair. He has also initiated King Faisal University initiatives on "Stop Food Loss and Waste" and the initiative to "Enhance the Kingdom's Position in the Global Food Security Index". Prof. Jameel M. Al-Khayri is a distinguished teacher and a researcher who contributes to the advancement of plant biotechnology utilization in food security. He is an internationally recognized book editor in agriculture innovations and sustainability. Dr. Azharia A. Elbushra is actively involved in economic policy analysis research related to food security. She is also a co-author of the University Food Loss and Waste initiative.

I would like to express my gratitude to the editors and contributors of this book for their unwavering dedication and tireless efforts in persistently working toward achieving food security in the Kingdom of Saudi Arabia. To all, my sincere congratulations on completing 2 volumes of this monumental reference book and wish them continued success.

Dr. Mohammed Abdul Aziz Al-Ohali
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Preface

Food and nutrition security is a significant concern for Saudi Arabia and the surrounding regions due to various challenges. These challenges include limited agricultural resources, land degradation, climate change, dependency on imports of most staple food products, and high levels of food loss and waste. This book aims to evaluate and analyze the status and future of food and nutrition security in Saudi, considering the prevailing food security challenges. Additionally, the book chapters analyze and assess the food systems, roles, and functions of different institutions related to food security. This book is of great importance to professionals, researchers, policymakers, and entrepreneurs working in the field of food and nutrition security in Saudi Arabia, the Gulf Cooperation Council (GCC), as well as national and international organizations. It provides a detailed analysis of the challenges and opportunities in ensuring food and nutrition security, as well as offering practical solutions and recommendations to address these issues. The book is also beneficial for graduate students studying agricultural sciences, economics, nutrition, and related fields that contribute to achieving food and nutrition security. The knowledge and recommendations outlined in this book can assist students and researchers in gaining a deeper understanding of the complex problems concerning food and nutrition security. Additionally, it can equip them with the skills and knowledge necessary to tackle these challenges in their future careers. Moreover, this book aligns with Kingdom Vision 2030, the strategies and programs focused on agriculture, food, and water security. It also corresponds with King Faisal University's institutional identity "Food Security and Environmental Sustainability".

The book consists of two volumes. Volume 1, subtitled "National Analysis of Agriculture and Food Security", focuses on assessing the current state of food security in Saudi Arabia. It investigates important agricultural and food resources, water security, food systems, domestic food production and consumption, organic crops, livestock, animal health, poultry, fisheries, strategic reserve, and transportation infrastructure and the contribution of higher education institutions to food security, population, agricultural extension, climate change, application of solar energy, agricultural mechanization, and smart agriculture. Additionally, a dedicated chapter highlights the role of the Arab Organization for Agricultural Development in promoting sustainable agricultural development and ensuring food security in the Arab world. Each chapter provides a thorough analysis using the most recent research and data available. It comprises 18 chapters contributed by 28 recognized scientists. The discussion of the topics is supported by 107 high-quality color figures and 49 tables.

Volume 2, subtitled “Macroeconomic Policy and Its Implications on Food and Nutrition Security”, examines how macroeconomic policies affect food and nutrition security in Saudi Arabia. The volume analyzes the impact of various policies, such as those related to the economy, agriculture, trade, food prices, oil revenue, food supply chain, finance, and agricultural investment abroad, on food and nutrition security in Saudi Arabia. Moreover, it explores topics in nutrition policy, including food consumption patterns, food processing, food safety and quality, food loss and waste, genetically modified food, edible insects, and the significance of date palm and Hassawi rice in ensuring food and nutrition security. Additionally, the book examines early warning systems for food security and the institutions responsible for ensuring nutrition security. It comprises 20 chapters contributed by 38 recognized scientists. Discussion of the topics is supported with 129 high-quality figures and 50 tables.

As food security is a complex issue that affects many different sectors, to effectively address it, a multidisciplinary approach is necessary. This book explores various topics related to food and nutrition security in Saudi Arabia. The wide range of topics covered in this book has several benefits. It provides a comprehensive understanding of food security by addressing a variety of issues. Moreover, the book provides ideas and recommendations for policymakers and researchers to address the challenges of ensuring food security in Saudi Arabia. Lastly, the book serves as a platform for sharing and exchanging knowledge in the field of food nutrition security in Saudi Arabia.

The chapters have undergone a rigorous review process to ensure high-quality presentation and scientific precision. The editors extend sincere appreciation and gratitude to the contributing authors for their conscientious participation and to Springer for the opportunity to publish this book.

Al-Ahsa, Saudi Arabia

Adam E. Ahmed
Jameel M. Al-Khayri
Azharia A. Elbushra

Acknowledgment The second editor Prof. Jameel M. Al-Khayri extends his appreciation to the Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Saudi Arabia, for supporting this work through Project No. GRANT5130.

Contents

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Dr. Adam E. Ahmed is Associate Professor of Agricultural Economics at the Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University. He obtained his B.Sc. in Agricultural Economics from the University of Khartoum, Sudan (1994), and M.Sc. in Agricultural Economics from the same university (1997). He obtained his Ph.D. at the University of Giessen, Germany (2004). He joined the Department of Agricultural Economics, Faculty of Agriculture, University of Khartoum (1994), as Teaching Assistant (1994–1998); Lecturer (1999–2000); Assistant Professor (2004–2009); and Associate Professor (2010 to present). Dr. Ahmed has pursued a variety of works including teaching, research, and community outreach. In these contexts, he has published two books, 6 chapters, more than 30 articles in peer-reviewed journals, and 20 conference papers. He is Founder of Albilad Bank Chair for Food Security in Saudi Arabia, as well as the Food Loss and Waste Research Chair. He is Initiator of King Faisal's initiative "Stop Food Loss and Waste" and the Initiative of strengthening Saudi Arabia's Rank in the Global Food Security Index. He had several consultancy assignments with FAO, WFP, ACSAD, and USAID. Dr. Ahmed participated in research projects funded by King Abdulaziz City of Science and Technology (KACST) in Saudi Arabia. He was PI of the national research project “Assessment of the patterns and determinants of breastfeeding and complementary feeding in infants in KSA”.

Prof. Jameel M. Al-Khayri is affiliated with the Department of Agricultural Biotechnology, King Faisal University, Saudi Arabia. He received B.S. in Biology in 1984 from the University of Toledo, M.S. in Agronomy in 1988, and Ph.D. in Plant Science in 1991 from the University of Arkansas. He is Member of the International Society for Horticultural Science and serves as National Correspondent of the International Association of Plant Tissue Culture and Biotechnology. He has authored 106 research articles and 58 chapters and edited several journal special issues. In addition, he edited 25 reference books on plant biotechnology, genetic resources, breeding, genomics, and nanotechnology. He has been involved in organizing international scientific conferences and contributed numerous research presentations. In addition to teaching, advising, and research, he held administrative responsibilities as Assistant Director of Date Palm Research Center, Head of Department of Plant Biotechnology, and Vice Dean for Development and Quality Assurance. Prof. Al-Khayri served as Member of Majlis Ash-Shura (Saudi Legislative Council) for the 2009–2012 term. He is interested in the role of biotechnology in enhancing food security and mitigation of the impact of climate change on agriculture.

Dr. Azharia A. Elbushra is Associate Professor of Agricultural Economics at the Department of Agribusiness and Consumer Sciences, King Faisal University, Saudi Arabia. She obtained her Ph.D. in Agricultural Economics from the University of Khartoum in 2007. She started her career as Teaching Assistant at the Department of Agricultural Sciences, College of Natural Resources and Environmental Sciences, University of Juba, Sudan, in 1994; Lecturer in 1998; and Assistant Professor in 2007. In August 2011, she joined the Department of Agricultural Economics and Agribusiness at the College of Agriculture, University of Bahri, Sudan, and was promoted to Associate Professor in April 2013. Her expertise is in the field of agricultural policy, project evaluation, food security, and quantitative modeling. She has published over 30 articles in esteemed journals, books, chapters, and conferences. Over the years, she has supervised numerous M.Sc. and Ph.D. students and has contributed to the peer-reviewing process worldwide. She also works as Consultant for local and international organizations and is Member of many scientific bodies related to her specialization. Dr. Azharia has actively participated in the implementation of various community-based initiatives.

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Chapter 1
Overview of Saudi Arabia Economy: Status Quo and Future Prospects

Adam E. Ahmed

Abstract To study and analyze the food security situation and related issues in Saudi Arabia, it is necessary to provide a brief analysis of the country's economy. This chapter gives an overview of the current status and future prospects of Saudi Arabia's economy, covering various factors related to food security such as the country's geographical location and area, population growth and distribution across age and administrative regions, and climate. The chapter provides a detailed assessment of Saudi Arabia's economy, including a discussion of its GDP growth rate and components, exports and imports, and most important trade partners. Additionally, the chapter highlights Saudi Arabia's position in the global economy. The chapter assesses the challenges and opportunities facing the agricultural sector in Saudi Arabia, including crop, livestock, poultry, and fish production, their contribution to achieving food security, and components of agricultural GDP. Other topics include the self-sufficiency ratio for agricultural products, agricultural development programs, and foreign and domestic agricultural investment. The chapter also discusses the role of Saudi Arabia in providing humanitarian aid in disaster and risk situations around the world. The chapter concludes by examining the prospects for the agricultural sector's growth and production in light of the Kingdom of Saudi Arabia's Vision 2030 and its accompanying directives and strategies for achieving food, water, and agricultural security.

Keywords Agriculture · Agricultural loans · Climate · Saudi Arabia economy · Food security · Humanitarian aid · Saudi Arabia 2030 Vision · Self-sufficiency

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1 Saudi Arabia Location and Area

Saudi Arabia is situated in the southwest of the Asian continent. To its west, it shares a border with the Red Sea and to the east, it is bordered by the Arabian Gulf, as well as the states of the United Arab Emirates and Qatar. To its north, it shares borders with Kuwait, Iraq, and Jordan, and to the south, it is bordered by Yemen and Oman. Saudi Arabia occupies around 80% of the Arabian Peninsula's area, which is estimated to be over 2.25 million km^2 (Nawab et al. 2011; Alyoubi and Essalmi 2022).

The total area of Saudi Arabia is more than 2 million km^2, which represents 70% of the semi-Arabian Peninsula, with an area of about 2.8 million km^2. The country is administered via 13 regions that are further divided into 106 governorates and 1377 centers, as indicated in Fig. 1. As per Table 1, the largest region of Saudi Arabia is the eastern region, covering an area of about 672,522 km^2—around 31% of the country's area, followed by the Riyadh region. The smallest region of the Kingdom is Al-Baha region, with a total area of around 10,000 km^2, which represents only 0.5% of the Kingdom's area (Table 1).

2 Climate

The Kingdom of Saudi Arabia has a varied topography due to its large size. The Tihama coastal plain stretches for 1100 km along the Red Sea, with a width of 60 km in the South, gradually narrowing as it heads north until it reaches the Aqaba Gulf. To the east of the Tihama plain lies the Sarawat mountain chain, rising 2743.2 m in the south and gradually declining until it reaches 914.4 m in the north. Many large valleys descend from the Sarawat Mountains towards the east and west, including Najran, Tathleeth, Bisha, Himdh, Rumah, Yanbu, and Fatimah. East of the Sarawat mountain chain lies the Najd plateau, extending to the Samman desert and Al-Dahna dunes eastward and southward to Dwaser Valley. This region runs parallel to the Empty Quarter desert, extending northward to the Najd plains, passing through the Hail region until it reaches the Great Nefud Desert, and then to the Iraqi and Jordanian borders (Mohorjy 1999). The Empty Quarter is located in the southeastern part of Saudi Arabia, covering an area of 640 thousand km and consisting of sand hills and lava fields. The eastern coastline has a length of 610 km and is characterized by large sandy areas and Salinas. According to the World Fact Book (2022), the climate of Saudi Arabia is harsh, dry, and desert-like, with extremely high temperatures. The main parts of Saudi Arabia receive small quantities of rainfall during the winter and spring seasons, but the southwestern mountains receive heavy rainfall in the summer. Almost throughout the year, the western coasts and mountains are characterized by high humidity, which decreases as you move inland. However, the General Authority for Statistics (2022) notes that Saudi Arabia has a diverse climate due to its varied topography, with the subtropical high-pressure system causing hot summers and cold winters, with frequent rainfall.

Fig. 1 Saudi Arabia administrative divisions. *Source* Wikipedia (2023). https://en.wikipedia.org/wiki/Saudi_Arabia

3 Population

The population of Saudi Arabia increased from 22.56 million in 2004 to 35.01 million in 2020 and then decreased to 34.11 million in the first half of 2021. Similarly, the percentage share of the Non-Saudi population out of the total population showed an increasing trend, with only 27.1% (6.12 million) in 2004, increasing to 38.1% (13.1 million) in 2019, and then decreasing to 36.4% (12.42 million).

Table 1 Saudi Arabia's area and population according to regions (2018—census results) and the latest official estimates

Name	Area (1000 km^2)	Population (Million)	Area (%)	Population (%)
Albahah	10	0.487	0.5	1.5
Aseer	77	2.262	4	6.8
Eastern region	673	5.029	31	15.0
Ḥa'il	104	0.716	5	2.1
Jazan	12	1.604	1	4.8
Jawf	100	0.521	5	1.6
Madinah	152	2.188	7	6.5
Makkah	153	8.804	7	26.3
Najran	150	0.596	7	1.8
Northern borders	112	0.375	5	1.1
Qaseem	58	1.456	3	4.4
Riyadh	404	8.447	19	25.3
Tabouk	146	0.931	7	2.8
Total	2150	33.414	100	100

Source Compiled by the author based on data from City Population (2022)

According to the recent analysis by Global Media Insight (GMI) in 2022, the population of Saudi Arabia is estimated to be 35.84 million with a population density of 16.67 people per km^2 and a median age of 32.4 years (Almulhim and Cobbinah 2023). Out of the total population, 20.7 million are male and 15.14 million are female, and 30.36 million reside in urban areas. In terms of age, more than half of the population (51.86%) falls within the age group of 25–54 years, while almost one-fourth of the population is in the age group of 0–14 years. Only 3.81% of the total population is 65 years old or above. In 2021, the annual birth and death rates in Saudi Arabia were recorded as 14.56 and 12.58 per thousand persons, for males, respectively, with a total fertility rate of 1.94 and female death of 17 per 100 thousand live births (Table 2).

The three most populous regions in the Kingdom are Makkah Al-Mukarramah, Riyadh, and the Eastern region, with populations of 8.8, 8.5, and 5 million, respectively. Together, these regions account for more than two-thirds of the total population in Saudi Arabia (Table 1). The least populous region in the Kingdom is the northern border region, with a population of 0.375 billion people, representing ~ 1.1% of the Kingdom's total population as of 2018.

Table 2 Population development in Saudi Arabia since 2004—in million people

Year	Saudi	Non-Saudi	Total population	Saudi (%)	Non-Saudi (%)
2004	16.44	6.12	22.56	72.9	27.1
2005	16.85	6.48	23.33	72.2	27.8
2006	17.27	6.85	24.12	71.6	28.4
2007	17.69	7.25	24.94	70.9	29.1
2008	18.11	7.67	25.79	70.2	29.7
2009	18.54	8.12	26.66	69.5	30.5
2010	18.97	8.59	27.56	68.8	31.2
2011	19.4	8.97	28.38	68.4	31.6
2012	19.84	9.36	29.2	67.9	32.1
2013	20.27	9.72	29.99	67.6	32.4
2014	20.7	10.07	30.77	67.3	32.7
2015	21.12	10.4	31.52	67.0	33.0
2016	20.06	11.68	31.74	63.2	36.8
2017	20.41	12.14	32.55	62.7	37.3
2018 (mid-year)	20.77	12.64	33.41	62.2	37.8
2019 (mid-year)	21.11	13.1	34.21	61.7	38.3
2020 (mid-year)	–	–	35.01	–	–
2021 (mid-year)	21.69	12.42	34.11	63.6	36.4

Distribution of the Saudi population according to age (2018)

Age group	Population (in Million)	Population (%)
0–14 years	8.72	24
15–24 years	4.69	13
25–54 years	18.59	52
55–64 years	2.47	7
65 years and above	1.36	4

Sources Compiled by the author based on data from General Authority for Statistics (2022) and GMI (2022)

4 Economy

The estimated value of natural resources owned by Saudi Arabia is 34.4 trillion USD, with a primary focus on oil (Statista 2021). Additionally, Saudi Arabia possesses other natural resources, including copper, feldspar, phosphates, silver, sulfur, tungsten, and zinc (World Fact Book 2022). Since its discovery in 1938, Saudi Arabia has become one of the main oil exporters in the world, with oil exports representing its primary source of income. According to the U.S. Energy Information Administration (2021), Saudi Arabia owns 15% of the world's proven oil reserves, making it the largest oil exporter in the world, with a production capacity of ~ 12 million barrels per day. It is also the largest crude oil producer within OPEC and the second-largest producer of total petroleum liquids worldwide, following the United States (U.S. Energy Information Administration 2021; Arafah 2022).

The Saudi Arabian economy is highly dependent on petroleum exports, which account for more than two-thirds (70%) of the country's total exports and 53% of the government's revenue in 2020. The COVID-19 pandemic led to a decline in the country's real GDP by 4.1% in the same year, largely due to a reduction in global demand for oil and voluntary cuts in oil production in compliance with the OPEC + agreement. Between 2018 and 2020, oil revenues in Saudi Arabia declined due to a decrease in both average crude oil prices and export volumes. According to the Energy Information Administration's estimates, net revenues from Saudi oil exports amounted to 202 billion USD in 2018, a decrease of 36 billion USD compared to the previous year. It is expected that the decline in oil prices and production will continue to affect the net oil export revenues of Saudi Arabia. Refining and chemical manufacturing of oil reserves in Saudi Arabia are primarily integrated with Saudi Aramco, owned by Saudi Arabia (U.S. Energy Information Administration 2021).

In 2020 Saudi Arabia's imports amounted to 146 billion USD, according to the Observatory of Economic Complexity (OEC). The top five import commodities for Saudi Arabia, as a percentage of the country's total imports, are cars (7.8%), followed by broadcasting equipment (3.8%), refined petroleum (2.7%), packaged medicaments (2.2%) and telephones (1.7%). Saudi Arabia imports commodities from many countries around the world, with the top five largest countries being China (31.8 billion USD), United Arab Emirates (18 billion USD), the United States of America (10.8 billion USD), Germany (6.79 billion USD) and India (6.37 billion USD), respectively, accounting for 22, 13, 8, 5 and 4% of total import. Each year, the largest and most powerful world economies are determined based on their Gross Domestic Product (GDP). The United Nations and the International Monetary Fund (IMF) prepare and publish an annual report on the GDP of most countries in the world. In 2020, Saudi Arabia ranked 18th based on GDP in current prices with a GDP of 1011 billion USD and ranked 17th when GDP is measured in current international dollars and purchasing power parity (PPP) amounting to 2018 billion USD (Knoema 2022).

It is expected that the Saudi Arabia will be one of the fastest-growing economies in the world in 2022, coinciding with the implementation of comprehensive and pro-business reforms, the sharp rise in oil prices, and the recovery of energy production from the stagnation that occurred as a result of the COVID-19 pandemic in 2020. Expectations indicate that the GDP will expand in 2022 by 7.6% (Mati and Rehman 2022). During the period of 2010–2021, Saudi Arabia's GDP growth rate showed a fluctuating pattern with the highest being 10.99% in 2011 while the lowest was in 2020 at − 4.34%. It then increased to 3.92% in 2021. The lowest growth rate in 2020 could be attributed to the impact of the COVID-19 lockdown (GASTAT 2021, 2022a, 2022b; Saudi Central Bank 2023). The pandemic caused high and increasing human costs worldwide, severely affecting all economic activities. As a result, the global economy was expected to contract by − 3% in 2020, which was much worse than the 2008–2009 financial crisis. However, the pandemic was

Table 3 Saudi Arabia GDP—an annual growth rate

Year	GDP growth rate
2010	4.76
2011	10.99
2012	5.43
2013	2.85
2014	4.03
2015	4.69
2016	2.36
2017	− 0.07
2018	2.76
2019	0.83
2020	− 4.34
2021	3.92

Sources Compiled by the author based on data from IMF (2020 and 2022) and Saudi Central Bank (2023)

expected to gradually fade in 2020, and the global economy would grow by 5.8% in 2021. Based on the report of the IMF, Saudi Arabia witnessed a strong recovery from the recession caused by COVID-19 pandemic. This strong recovery was driven by several factors, including liquidity and fiscal support, reform momentum, and increased oil production coupled with its high prices. The report indicated that the Saudi economy achieved a growth rate of 3.2% in 2021 as a result of the recovery of the non-oil manufacturing, retail, and commercial sectors. Furthermore, the report revealed a decrease in the unemployment rate among Saudis, reaching 11%, with a decrease of 1.6% compared to 2020, owing to a high employment rate of Saudis, especially women, in the private sector (IMF 2022) (Table 3).

Table 4 reveals that Saudi Arabia's exports to China, India, Japan, South Korea, and the USA accounted for almost two-thirds of its total export value of 205,433 million USD in 2019. The total value of Saudi Arabia's imports in 2019 amounted to 103,241 million USD, of which one-quarter came from China (26.2%). The USA followed with a share of 16.5%, UAE with 10%, Germany with 6.8%, and Japan with 6.3%.

Re-exported goods are goods that have been previously imported and have undergone all necessary customs procedures for export without significant modifications. This information comes from the General Authority for Statistics in 2023. Table 5 shows the percentage of goods that were re-exported from GCC states to Saudi Arabia, as well as the percentage of imports from Saudi Arabia to GCC states. The UAE is Saudi Arabia's primary trading partner among GCC states, with 87% of the total value of goods re-exported from GCC states to Saudi Arabia in 2014 and increasing to 95% by 2018. Similarly, UAE imports from Saudi Arabia made up approximately half of the total GCC states' imports from Saudi Arabia in 2014 and about two-thirds in 2018, as shown in Table 5.

Table 4 Saudi Arabia's main imports and exports partner countries (2019)

Country	Import (%)	Country	Export (%)
China	26.2	China	23.3
U.S.A	16.5	India	13.3
United Arab Emirates	10.0	Japan	13.0
Germany	6.8	South Korea	10.1
Japan	6.3	U.S.A	6.5
India	6.3	United Arab Emirates	6.3
France	4.9	Singapore	4.2
Italy	4.2	Netherlands	3.7
South Korea	3.9	Taiwan	3.4
United Kingdom	3.0	Bahrain	3.4
Turkey	2.9	Egypt	3.3
Thailand	2.3	Belgium	2.7
Egypt	2.3	Thailand	2.4
Brazil	2.2	Spain	2.2
Canada	2.2	France	2.1
Total (value Million USD)	103,241	Total (value Million USD)	205,433

Source Compiled by the author based on data from General Authority for Statistics (2023)

5 Agricultural Sector

Agriculture in Saudi Arabia is faced with a number of challenges. These include a dry climate with minimal rainfall, sandy soil that has low fertility and high salinity, which can lead to plant and animal diseases, and a scarcity of water sources for agricultural, residential, and industrial use (MEWA 2019). However, despite these challenges, the agricultural sector plays a crucial role in achieving the Kingdom's Vision 2030. It is the main means of ensuring food security, stabilizing food prices, as well as contributing to rural and economic development. Furthermore, the sector serves as the primary source of raw materials and production inputs for almost one thousand food and beverage factories. Saudi Arabia is one of the largest exporters of dates in the world and a significant regional exporter of shrimp. Agriculture provides an essential source of income for over one million Saudi citizens, particularly those living in rural areas, and contributes 4% to the non-oil GDP or 64 billion riyals of the nominal domestic product (NDP) (MEWA 2018).

Over the past decade, the agricultural sector has made countless advancements. Saudi Arabia has successfully implemented vision programs, while the National Environment Strategy, the National Water Strategy, and the Food Security Strategy have all been adopted. In addition, numerous programs and studies have been approved to achieve the agricultural strategy, notably the Sustainable Agricultural Rural Development Program and the Program for Redirecting Agricultural

Table 5 Goods re-exported from GCC states to Saudi Arabia and imports of GCC states from Saudi Arabia (%)

	Bahrain		Kuwait		Oman		Qatar		U.A.E		GCC (Million USD)	
	Re-exported	Imports	Re-exported	Imports	Re-exported	Imports	Re-exported	Imports	Re-exported	Imports	Re-exported	Imports
2014	9	9	1.8	15	1.3	13	2.3	14	87	49	14,477	9944
2015	17	8	2.2	14	1.4	13	2.5	14	78	52	16,529	10,307
2016	10	8	2.4	14	0.5	8	1.8	13	85	58	11,703	10,761
2017	5	8	2.4	16	1.1	9	0.6	5.4	91	61	11,626	11,301
2018	4	9	1.2	17	0.5	8	0.0	0.1	95	65	13,815	11,672

Source Compiled by the author based on data from General Authority for Statistics (2023)

Subsidies (MEWA 2018). Despite local production only meeting one-third of the Kingdom's total caloric energy requirement, Saudi Arabia has several opportunities to increase the percentage of local production that contributes to the national calories' requirement. These opportunities include expanding the production of commodities in which the Kingdom has a comparative advantage, reducing food waste and loss throughout the food supply chain, increasing productivity, and adopting good agricultural practices.

According to flash estimates by GASTAT, Saudi Arabia achieved the highest GDP growth rate of 8.7% in the year 2022 over the past decade. This increase in growth rate is attributed to both oil and non-oil activities, with increases of 15.4 and 5.4%, respectively (MEP 2023). Furthermore, a recent report released by the Ministry of Environment, Water, and Agriculture in 2021 indicates that agricultural output in Saudi Arabia has increased in size, with a value of 19.26 billion USD and a growth rate of 7.8% compared to the previous year. The gross domestic product has reached about 0.8 trillion USD, recording the highest growth in over five years (MEWA 2022; MEP 2023).

The Ministry of Environment, Water and Agriculture has confirmed that the agricultural sector's growth is a result of plans and strategies that align with the goals of the Kingdom's Vision 2030, as well as the sector's recovery from the Covid-19 crisis. The agricultural output amounted to approximately 17.41 billion USD in 2017, 17.46 billion USD in 2018, 17.65 billion USD in 2019, and 17.88 billion USD in 2020. In 2021, the sector's contribution to the GDP was 2.3%, while its contribution to the non-oil GDP was 3.6%, constituting a 0.2% increase compared to 2020. Moreover, the agricultural output contributed to 3.4% of the economy in 2021 (MEWA 2022).

The Ministry has reported that Saudi Arabia achieved a trade balance surplus of 123.3 billion USD, indicating an increase from 2020's 35.87 billion USD due to an upsurge in exports in 2021, valued at 266.67 billion USD. The report highlights a 3.5 USD billion increase in agricultural exports, with a surge of 110.67 million USD compared to 2020. Furthermore, the agricultural trade balance deficit decreased to 17.22 billion USD in 2021, down from 19.57 billion USD the prior year because of fewer agricultural imports. The Ministry has designed and embraced flexible agricultural plans and strategies to promote local content, boost self-sufficiency rates, and attain food security, including implementing the Food Security Strategy and the Rural Development Program while utilizing innovation and technology to enhance productivity and attain the efficient use of natural resources and agricultural inputs. These initiatives are intended to foster sustainable and comprehensive agricultural and food systems and achieve sustainable growth, aligned with the Kingdom's Vision 2030. The Ministry attributes the progress in the agricultural sector to support programs that target the goals set by the National Strategy for Agriculture and offer investment opportunities to boost productivity and provide food products with a comparative advantage in local markets. This has led to high rates of self-sufficiency in several food products, including animal products such as milk, table eggs, poultry meat, fish, red meat, and plant products such as dates, vegetables, and fruits (MEWA 2022; MEP 2023).

During the Arab-Hellenic Food Conference in 2021, the Undersecretary of the Ministry of Environment, Water, and Agriculture confirmed that Saudi Arabia has taken significant measures to enhance agricultural development and food security. These measures intend to combat climate change and water shortage, foster better food security indications and consumption patterns, decrease waste, and attain high degrees of self-sufficiency for various strategic food items in the local market. Moreover, Saudi Arabia is raising the levels of operation and production for agricultural and food systems (Table 6).

5.1 Saudi Arabia Food Products Self-sufficiency Ratio

The results outlined in Table 7 demonstrate that the agricultural industry has achieved high levels of self-sufficiency ratios (SSR) across various plant products. Specifically, the self-sufficiency rate for dates, eggplant, figs, cauliflower, beans, cucumber, okra, cabbage, and watermelon was almost or above 100%. Additionally, SSR values varied from 99 to 80% for watermelon, melon, pumpkins, and papaya. However, the self-sufficiency rates for citrus fruits, pomegranates, carrots, and most cereals and fodder crops were relatively low, with < 50% due to limited water resources. Consequently, the Ministry opted to reduce the cultivation areas of these crops to increase irrigation water efficiency, reduce waste, and enhance economic efficiency. A recent report from the General Authority for Statistics in 2021 also showed the self-sufficiency rates for crucial animal, poultry, and fish products. Notably, fresh dairy products had the highest self-sufficiency rate among animal products, reaching 121%, followed by table eggs at 112%. Meanwhile, fish's self-sufficiency rate was only 40% during the same period as evidenced by Table 7.

Table 7 indicates that Saudi Arabia targeted specific agricultural commodities for importation to help bridge the gap between total consumption and domestic production. The objective was to ensure food security by optimizing consumption and enhancing agricultural resource efficiency in production. According to Table 8, the total value of agricultural GDP and fishing in Saudi Arabia was a mere 10,571 million USD at current prices in 2005. However, with a rising growth rate, it had reached 17,453 million USD by 2018. Notably, the contribution of plant production to the agricultural GDP and fishing industry decreased from 55% in 2005 to just 28% in 2015, before ultimately increasing and reaching almost one-third in subsequent years. Table 8 additionally showcases the percentage contribution of plant, animal, and fishing production to the agricultural GDP and fishing industry from 2005 to 2018.

Table 9 shows that vegetable production increased from 1239 thousand metric tons in 2018 to ~ 1623 metric tons in 2020. Despite a decrease in vegetable cultivation area from 99,000 ha in 2018 to 74 thousand hectares in 2020, there was an increase in vegetable production. This increase can mainly be attributed to an increase in

Table 6 Water demand by user (percent of the total)

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Residential (%)	13	12	12	12	12	13	13	14	23	26	25
Industrial (%)	4	4	4	4	4	4	4	6	9	12	4
Agriculture (non-renewable water) (%)	83	84	84	84	84	83	82	80	68	62	71
Total (million cubic meters)	19,193	20,884	22,260	23,416	24,833	23,934	23,350	23,828	15,393	13,809	14,264

Source Compiled by the author based on the data from the Saudi Arabia statistical book (2021)

Table 7 Saudi Arabia's self-sufficiency ratio in plant products for the year 2021

	Local production	Imports	Export	SSR (%)
Potato	578,108	48,253	16	92
Tomato	620,866	186,785	553	77
Onion	297,974	274,538	534	52
zucchini	64,650	1631	1549	100
cucumber	188,558	1414	3145	101
Pepper	108,057	29,539	3464	81
Carrot	24,500	43,685	3826	38
Okra	25,327	319	753	102
Watermelon	624,110	7065	57	99
Eggplant	112,000	835	6443	106
Cabbage	14,210	1635	2899	110
Cauliflower	18,500	1308	2548	107
Melon	55,119	11,885	0	82
Pumpkins	62,100	3788	0	94
Beans	10,800	631	1076	104
Dates	1,565,830	19,817	258,098	118
Citrus fruits	116,800	657,896	10,403	15
Mango	88,650	60,049	900	60
Grapes	106,400	71,842	455	60
Banana	22,200	496,683	5440	4
Fig	27,536	258	2036	107
Pomegranate	30,100	62,781	3365	34
Papaya	4717	517	253	95

Animal, fish and poultry products self-sufficiency Ratio (2021) (1000 Mt)

	Local production	Consumption	SSR (%)
Red meat	178	414	43
Poultry meat	930	1409	66
Milk	2600	2149	121
Eggs	359	321	112
Fish	99	246	40
Shrimp	78	53	149

Production, export and import in thousand mt

Source Compiled by the author based on the data from Ministry of Environment, Irrigation, and Agriculture (2023)

Table 8 Percent contribution of plant and animal production and fishing to agricultural GDP and fishing (2005–2018)

Year	Plant	Animal	Agricultural	Fish	Agricultural GDP and fishing (million USD)
2005	55	25	80	20	10,571
2006	55	27	82	18	11,098
2007	54	29	83	17	11,515
2008	55	33	88	12	12,043
2009	57	34	91	9	12,247
2010	47	34	81	19	13,946
2011	46	32	78	22	14,575
2012	45	29	74	26	15,303
2013	45	34	79	21	16,107
2014	29	31	60	40	16,844
2015	28	32	59	41	17,138
2016	30	33	63	37	17,321
2017	31	33	64	36	17,411
2018	32	34	66	34	17,453
Average	43	31	75	25	14,541

Source Compiled by the author based on the data from General Authority for Statistics (2022) and Saudi Central Bank (2022)
Saudi Central Bank (2022). Statistical Report https://www.sama.gov.sa/en-US/EconomicReports/Pages/report.aspx?cid=123
https://www.stats.gov.sa/en/823

productivity. However, during the same period, the area used for wheat and barley production declined. Wheat cultivation decreased from 95,000 ha in 2018 to 87 thousand hectares in 2020. On the other hand, green fodder production increased more than threefold in 2020, with 207 thousand hectares in comparison to 2018.

The number of cattle and buffalo slaughtered increased from 271 in 2018 to 312 thousand in 2019, but then decreased to only 210 thousand in 2020. In contrast, the number of goats and sheep slaughtered increased by more than a quarter in 2020 compared to 2018. The production of sheep and goat meat also increased by more than a fifth in 2020 (210 thousand) compared to 270 thousand in 2018. Moreover, fish production increased from 141 in 2018 to 162 thousand metric tons in 2020, representing a growth rate of roughly 15% compared to 2018 (see Table 10).

Table 10 displays an increase in the number of livestock in Saudi Arabia from roughly 13.5 million in 2018 to 16.05 million, resulting in a 19% growth rate. From 2018 to 2020, this increase was observed in goats, cows, and camels, with growth rates of 67, 47, and 2.5%, respectively. Different types of meat production echoed this upward trend, with red meat increasing by 7.2%, poultry by 27%, milk by 23%, and fish by 15% in comparison to 2018. However, there was also a 5.4% decrease in camel meat production in 2020. In total, sheep represented 60%, goats a third, camels

Table 9 Plant production area and productivity (area: 1000 ha, yield: kg/ha production: 1000 mt trees: 1000)

Products	2018			2019			2020		
	Production	Productivity	Area	Production	Productivity	Area	Production	Productivity	Area
Total cereals	1200	4845	248	1345	5497	245	1181	4860	243
Wheat	518	5464	95	534	6068	88	555	6376	87
Barley	505	5588	90	628	6854	92	438	5374	82
Maize	45	5677	8	48	6077	8	59	4471	13
Sorghum and millet	132	2424	55	135	2365	57	129	2109	61
Roots and tubers	425	235	18	472	24,768	19	561	28,804	19
Potatoes	425	23,549	18	472	24,768	19	561	28,804	19
Total pulses	16	3453	5	17	3566	5	15	3029	5
Oil seeds and olives	5	5927	2	6	2811	2	371	17,160	35
Vegetables	1239	12,572	99	1469	16,748	88	1623	22,038	74
protected agriculture	2648		111	2648		111	2648		111
Green fodder	1390	16,466	84				4557		207
	Production	Fruiting trees	Area	Production	Fruiting trees	Area	Production	Fruiting trees	Area
Fruits	2234	–	154	2462	–	157	2342	–	213
Dates	1428		116	1540		118	1542		153
Citruses	40		4	35		4	57		3

Table 10 Saudi Arabia livestock, poultry, and fish production

	2018	2019	2020
Total livestock	13,492	14,191	16,047
Cattle	477	567	700
Sheep	9396	9420	9447
Goats	3608	3711	6100
Camels	488	493	500
Slaughtered Cattle and Buffaloes	271	312	210
Slaughtered goats and sheep	6505	6565	8167
Slaughtered camels	480	493	490
Cattle and Buffalo meat production	42	43	42
Sheep and goat meat production	121	122	146
Camels meat production	106	109	100
Red meat production	269	274	288
Poultry meat production	710	800	901
Chickens numbers	194	197	202
Milk production	2361	2683	2911
Egg production	345	382	350
Fish production	141	143	162

Animals and slaughtered animals:1000 heads, production:1000 mt, birds: million
Source Compiled by the author based on the data from Arab organization for agricultural development (2022)

4%, and cows only 3% of the total livestock population of 16.04 million in Saudi Arabia in 2020. According to GASTAT's latest report (2023), the value of exported goods is computed by adding the value of agricultural commodities to other delivery costs or export office expenses, while the cost of imported goods is determined by adding the product cost to other expenses, such as insurance, transportation, and freight costs, until their arrival at the importing countries' ports. As evidenced in Table 11, both agricultural imports and exports in Saudi Arabia decreased from 2016 to 2021. In 2021, imports and exports fell to 18.9 and 3.1 million USD, respectively, from 22.7 and 3.6 million USD in 2016.

The term 'value of agricultural loans' refers to loans given to finance the cultivation of various crops and orchards, the purchase of fishing equipment, the promotion of agricultural tourism, the establishment of veterinary clinics, the provision of vegetable carts, and the support of apiaries. According to the Agricultural Statistics Bulletin Tables (2023), the amount of loans distributed to stakeholders increased by more than fourfold between 2016 and 2021, from 121 million USD in 2016 to 539 million USD in 2021.

Table 11 The total quantity and value of imports of agricultural crops and livestock, 2016–2021 (Quantity: Million MT, Value: Million USD, Area 1000 ha)

KPIs	Unit	2016	2017	2018	2019	2020	2021
Self-sufficiency ratio of dairy products	%	–	–	–	126	121	121
Self-sufficiency rate of dates	%	–	–	–	–	111	118
The total amount of import of agricultural crops and livestock	mt	28.72	29.67	28.35	24.83	29.1	20.0
The total amount of export of agricultural crops and livestock	Million mt	3.24	3.03	2.99	3.08	4.42	2.65
Total value of import of agricultural crops and livestock	Million USD	22.7	21.8	21.4	21.7	22.9	18.9
Total value of export of agricultural crops and livestock	Million USD	3.6	3.5	3.5	3.5	3.4	3.1
Organic cultivation area for agricultural crops	Thousand ha	16.22	16.98	18.64	24.52	26.63	27.1
Production of organic cultivation for agricultural crops	Thousand mt	56.26	52.84	44.63	61.44	98.56	98.8
Amount of loans distributed to the stakeholders' sectors	Million USD	121	165	205	488	475	539
Bank credit granted by a bank (agriculture and fishing)	Million USD	3407	3266	3941	3907	4363	3723

Source Compiled by the author based on the data from Agricultural Statistics Bulletin (2023a, b)

5.2 *Saudi Arabia Agricultural Investment*

The Saudi Agricultural and Livestock Investment Company (SALIC) is a joint-stock company located in Saudi Arabia. It is owned by the Public Investment Fund and was established by a royal decree in 2009 with the aim of contributing to the country's food security strategy. SALIC's investment activity is focused domestically and abroad in order to stabilize prices and provide food products. This is achieved through the formation of subsidiary companies or partnerships at the national, regional, and international levels (SALIC 2023a). SALIC began investing in 2012 and has partnered with various international companies in agriculture and trade across several countries including Ukraine, Canada, India, Australia, Brazil, Singapore, and Britain. On the local side, SALIC has invested in companies such as Grain Companies, Almarai, Nadec, and Fisheries. To achieve long-term food security, SALIC has identified 12 strategic commodities in Saudi Arabia and other regions. These commodities include wheat, barley, rice, corn, soybean, fodder, red meat, poultry, aquaculture, edible oil, sugar, and dairy products (SALIC 2023b).

One of the objectives of the Food Security Initiative in Saudi Arabia is to implement a program for foreign agricultural investment. The goal is to diversify and stabilize food supplies, establish strategic partnerships with host countries, and support private sector participation in agricultural investment abroad. The Agricultural Development Fund (ADF) provides loans for foreign agricultural investment as part of this initiative. The loans can cover up to 60% of the project cost for a period of 10 years with a 2-year grace period, and can be disbursed in either Saudi riyals or US dollars. Repayments can be made according to the cash flow of each project (ADF 2023a, 2020). The program primarily targets crops such as alfalfa, corn, and wheat, and secondary crops include sugar, rice, soybeans, edible oil, and barley.

The ideal loan amount is between 30 and 75 million USD. To be eligible for this loan, the applicant's company must have Saudi ownership, which requires more than 50% of the company's shares to belong to a Saudi entity or individual. The applicant must also have experience in international agricultural investment and export at least 50% of the crop produced to the Kingdom to contribute to achieving food security in Saudi Arabia.

It should be noted that the first step in this initiative was the approval of the Foreign Agricultural Investment Program, which granted loans totaling 172 million USD during the first year of the program's launch. The intention was to cultivate and supply barley, wheat, corn grain, oilseeds, and soybeans from the Republic of Ukraine. Additionally, a project for a national company specializing in agricultural investment and animal production was approved to invest in Sudan (ADF 2020). In October 2022, the Saudi Agricultural Investment and Livestock Production Company, SALIC, provided the initial batch of 250 thousand metric tons of wheat purchased from Saudi investors abroad, which constituted only 20% of the planned total quantity. The ADF had signed numerous financing contracts with selected firms with a total value exceeding 411 million USD under the initiative of funding the import of targeted agricultural items to achieve food security in Saudi Arabia. Specifically, the ADF's financing was earmarked for yellow corn, soybeans, and barley (ADF 2023b). In 2023, the ADF granted financing loans and credit facilities amounting to 579 million USD as a development loan for small farmers. The loans were allocated to vegetable production in greenhouses, broiler poultry production, fish breeding, and production, and date manufacturing in different areas of the country. The funds aimed to enhance the strategic stock, ensure the stability of food supply chains, and offset any shortages that may occur in the supply of agricultural commodities and products (ADF 2023c).

Table 12 presents the various types of agricultural, poultry, and animal projects that received funding from the fund, along with the number of loans granted to each project from 2016 to 2021. The number of projects funded by the ADF increased from 27 in 2016 to 60 in 2021. Similarly, the total amount allocated for financing these projects increased more than eightfold, from 52 million USD in 2016 to 433 million USD in 2019. In total, the ADF funded 271 projects between 2016 and 2019. Regarding the agricultural, poultry, and animal-funded projects, broiler chicken represented 33.1% of the total number of projects, followed by greenhouse projects at 19% and agricultural products marketing centers at 14%. In terms of the total amount of funding allocated to these projects between 2016 and 2021, marketing centers for agricultural products received the highest amount, with 379 million USD (29%), followed by greenhouses at 279 million USD (23%), and broiler chicken at 247 million USD (19%).

6 Saudi Arabia Humanitarian Aids Under Disaster and Risk Situation

Saudi Arabia plays a significant and innovative role with regard to all nations worldwide. In an effort to alleviate human suffering and promote decent and healthy living conditions, the King Salman Humanitarian Aid and Relief Centre (KSHARC) was established in 2015. The centre has become an international hub that specializes in relief and humanitarian efforts. It operates under the guidance and patronage of the Custodian of the Two Holy Mosques, King Salman bin Abdulaziz. The centre's work aims to provide assistance and relief to those in need across the globe. The KSHARC uses advanced monitoring mechanisms and efficient transportation methods and works closely with United Nations organizations as well as international and local non-profit organizations in the countries that require intervention. The centre tailors projects and programs to the specific needs and conditions of the beneficiaries. Their aid covers various sectors, including relief security, camps management, shelter, early recovery, protection, education, water and sanitation, nutrition, health, humanitarian and emergency relief coordination, logistics, and emergency telecommunication (KSHARC 2023). The center operates on various principles, which demonstrate the Kingdom's commitment to aiding the less fortunate with humanitarian motives. This is achieved by collaborating with recognized organizations, groups, and internal efforts to offer professional and efficient relief programs to all centre employees. It ensures that high-quality assistance reaches its intended recipients (KSHARC 2023). The KSHARC has completed 2246 initiatives in 12 sectors and 90 countries, costing a total of 6053 million USD by the end of last year (2022). Two-thirds of the projects focused on food security and health plans, which accounted for over half of the overall expenses across various sectors (Table 13).

The Center has allocated food security projects to Africa and Asia, which are the top two continents receiving the projects. These continents account for 95% of the total number of food security projects. On the other hand, Arab countries have secured a portion of the food security projects from KSHARC Center. They are responsible for 445 out of the total projects. The Arab countries' share of the food security projects provided by KSHARC amounts to 44% of the total, with Yemen leading with 130 projects, followed by Syria with 96, Somalia with 44, Jordan with 20, Lebanon with 18%, and Sudan with 17%.

Table 12 Agricultural development fund contribution financing agricultural, poultry, and livestock projects during the period 2016–2021(amount of loan: million USD)

	2016		2017		2018		2019		2020		2021		Total	
	No. of projects	Amount of loan	No. of projects	Amount of loan	No. of projects	Amount of loan	No. of projects	Amount of loan	No. of projects	Amount of loan	No. of projects	Amount of loan	Total number	Total amount of loan
Broilers	14	18.84	11	29	9	16	30	74	13	22	22	88	99	247
Mothers of broiler chickens:	2	9.27	2	9	2	16	2	14	1	12	1	17	10	76
Laying hens	1	5.33	5	11	2	4	3	13	3	3	2	9	16	45
Hatcheries	0	0.00	2	10	1	2	1	10	0	0	2	8	6	29
Poultry slaughterhouse	0	0.00	1	0	0	0	0	0	1	3	2	19	4	22
Green houses	5	6.00	5	15	8	39	5	33	15	102	14	102	52	297
Date factories	2	5.60	3	4	2	6	5	7	3	9	3	5	18	37
Fattening Calves	0	0.00	2	2	2	1	1	1	1	3	2	2	8	9
Milk production	2	6.59	1	11	0	0	0	0	9	48	1	3	13	68
Agricultural products marketing center	1	0.18	1	1	9	43	17	266	1	18	8	50	37	379
Shrimp Breeding	0	0.00	1	6	0	0	0	0	1	33	1	2	3	41
Fish farming with enclosures	0	0.00	1	34	1	16	0	0	1	0	2	6	5	57
Total	27	51.8	35	133	36	143	64	417	49	253	60	311	271	1308

Source Compiled by the author based on the data from Agricultural Statistics Bulletin Tables (2023)

Table 13 KSHARC projects (completed-ongoing) by sector

Project sector	No. of projects	Cost (M USD)	No. of projects%	Cost M USD%
Food security	734	1917	32.7	31.7
Health	764	1131	34.0	18.7
Humanitarian and emergency relief coordination	53	860	2.4	14.3
Protection	52	211	2.3	3.5
Nutrition	23	177	1.0	2.9
Camp coordination	204	529	9.1	8.8
Multi-cluster	104	381	4.6	6.3
Water, sanitation, and hygiene	77	256	3.4	4.2
Education	113	212	5.0	3.5
Logistics	16	60	0.7	1.0
Early recovery	58	296	2.6	4.9
Charitable assistance	47	8	2.1	0.1
Emergency telecommunications	1	16	0.04	0.3
Total	2246	6053	360.0	6053

Food security projects	Number of projects	Number of projects (%)	Costs (%)
Africa	252	34	31
Asia	448	61	68
Europe	21	3	0.05
North America	13	2	2
Total	734		100
Arab Countries	347		

Source Compiled by the author based on the data from KSHARC 2023

7 Saudi Arabia's Directives for the Main Agricultural Products

The Saudi economy is expected to flourish due to the increase in oil prices, the expansion of private investment, and the implementation of economic reform programs based on the Kingdom's Vision 2030. The Saudi current account has achieved its highest surplus in the past ten years and Saudi Arabia has managed to keep inflation under control. Given the current state of global economic uncertainty and its impact on financial conditions and oil prices, Saudi Arabia has been making efforts to increase financial margins and diversify its sources of income rather than relying solely on oil. It is anticipated that financial reforms, which are ongoing and regularly renewed, will promote investment in various sectors by carefully calibrating investment programs, improving financial and external sustainability, and implementing structural reform programs that foster strong, inclusive, and sustainable economic growth. According to a report titled "Mission Concluding Statement" (2023) from the World Bank, the Kingdom of Saudi Arabia has been identified as the fastest-growing economy within the G20 in 2022. This growth can be attributed to an increase in oil production, resulting in a growth rate of about 8.7%. Non-oil total increased by 4.8% and is expected to exceed 5% by 2023. Saudi Arabia has also achieved a record-low unemployment rate of 4.8%, with a 50% reduction in youth unemployment to 16% compared to 2020–2021. Additionally, female participation in the labor force exceeded the target percentage of 30% set in Vision 2030, achieving a 6% increase. Inflation in Saudi Arabia has declined, reaching an annual rate of 2.7% in April 2023 compared to 3.4% at the beginning of the year. The report recommends several financial policies to strengthen and prosper the Saudi economy, including energy price reforms, the development of an asset and liability management framework, and monetary policies that ease liquidity pressures. Furthermore, structural reforms are suggested to achieve strong, sustainable, and environmentally friendly growth, reducing the Kingdom's dependency on oil through targeted interventions and incentives. Investment programs should be improved to introduce changes in the selection of government projects and evaluation methods, increasing investment efficiency in the Kingdom, and reducing emissions. The report acknowledges that fiscal adjustment in the medium term 2023–2030 will be necessary to ensure justice between generations. This includes collecting non-oil revenues, strengthening the management of tax expenditures, and rationalizing their spending (IMF 2023).

Saudi Arabia has launched a comprehensive plan for the country called "Saudi Arabia Vision 2030." The plan consists of three pillars: vibrant society, thriving economy, and ambitious nation (Brans 2023). Each pillar has six overarching objectives, further broken down into 27 branch objectives. These branch objectives are then subdivided into 96 strategic goals. The vision will be implemented through various vision programs. Saudi Vision 2030 has multiple strategic goals and commitments, including increasing non-oil exports to make up 50% of the non-oil GDP, ranking Saudi Arabia 15th in the world's largest economy, advancing from 49 to 25th in the logistics performance index, increasing the Public Investment Fund's assets from 160 billion USD to ~ 1.88 trillion USD, increasing foreign direct investment to 5.7% GDP, and augmenting non-oil government revenues to 266 billion USD (Saudi Vision 2023). It is essential to mention that the vision has many transformational programs to pave the way for its strategic goals, like strategic partnerships, government restructuring, improving public sector governance and privatization, ensuring financial stability, project management, reviewing regulations, measuring performance, restructuring the Public Investment Fund, human capital development, and national transformation. One of the top commitments of the vision is to preserve vital resources by establishing strategic food reserves that could be used during emergencies securely. To reach this purpose, the vision proposes promoting aquaculture, cooperating with countries with natural resources like fertile land and abundant water, prioritizing water utilization by areas with renewable water sources, and coalescing with consumers, food producers, and distributors to conserve resources and diminish waste. All these endeavors and commitments are connected to the agricultural sector, food systems, and the food security pillars embracing availability, accessibility, utilization, and stability.

Since the implementation of Saudi Arabia's Vision 2030, there have been several achievements that have supported economic growth and empowered citizens, with numerous future opportunities planned. Eleven programs have been created to bring this vision to life by transforming them into action plans, resulting in many successes across the three primary pillars of the Saudi Vision 2030 The Ministry of Environment, Water, and Agriculture (2017) developed the National Strategy for Agriculture 2030, which led to specific directives for the future of agricultural products in the Kingdom of Saudi Arabia. These products include grains, vegetables, dates, fruits, red meat, poultry meat, fish, milk, and eggs. The Saudi Grains Organization (SAGO) has directed the purchase of wheat from farmers between 2019 and 2024 as an alternative for fodder, at a maximum of 700 thousand mt (~ 20% of self-sufficiency). In terms of vegetables, the directives aim to increase the current self-sufficiency rate from 70 to 100%, adopt recommendations of comparative advantage and modern methods to improve productivity, encourage promising crops and organic agriculture, and continue to encourage protected agriculture and improve its production efficiency. Regarding dates, the directives include maintaining a high level of self-sufficiency (115%), developing value-added exports, encouraging the use of modern methods to improve productivity, and focusing on preventing and controlling the red palm weevil. The value of dates in the Kingdom of Saudi Arabia amounts to 2 billion USD, contributing about 12% of the agricultural GDP and 0.4% of the non-oil GDP. The Kingdom of Saudi Arabia ranked first in the value of date exports in 2021, amounting to 320 million USD, which reflects the high production capacity and enhances the contribution of agricultural production in increasing non-oil exports. This is subsequently reflected in the improvement of production and exports of dates in the future (IOFS 2022).

Regarding green fodder, the instructions were to decrease domestic production to less than a quarter of the current need for green fodder and to develop foreign investments and storage capacity for green fodder. Similarly, for fruit products, efforts will be made to increase the current self-sufficiency rate from 25 to 40% by adopting recommendations based on comparative advantage and modern methods to enhance productivity and encourage the cultivation of promising crops and organic fruit crops. Concerning red meat and poultry meat, directives have been given to maintaining the current self-sufficiency ratio of 25–30% for red meat, while also reducing the number of livestock heads by 40%. The focus will be on organizing the sector, doubling current productivity, and cutting waste. For poultry meat, the goal is to raise the current self-sufficiency rate from 47% to at least 65%.

On the other hand, there are specific directives in place regarding fish, milk, and egg products. These directives aim to increase the percentage of fish production from 110 to 600 thousand metric tons from the aquaculture and fisheries sector. This increase in production is accompanied by the development of exports and it contributes towards maintaining the current self-sufficiency ratio for both fresh milk (122%) and eggs (115%).

Saudi Arabia has invested 24.8 billion USD to boost food production and exports and achieve food security. This investment is part of a larger plan to strengthen the agricultural sector, increase domestic production and export, and enhance food supply. Approximately 25 billion USD have been allocated towards the development of industries, while 2 billion USD have been directed towards loans provided by the Saudi Agricultural Development Fund to support the different agricultural sectors. In 2017, the Ministry of Environment, Water, and Agriculture developed the National Strategy for Agriculture 2030, which included specific directives for different types of agricultural products, such as grains, vegetables, dates, fruits, red meat, poultry meat, fish, milk, and eggs. The Saudi Grains Organization (SAGO) aims to purchase up to 700 thousand mt of wheat from farmers between 2019 and 2024, which represents about 20% of self-sufficiency. The goal for vegetables is to increase self-sufficiency from 70 to 100%, adopt recommendations of comparative advantage and modern methods to improve productivity and encourage promising crops and organic agriculture. Dates are another important agricultural product for Saudi Arabia, and efforts are being made to maintain a high level of self-sufficiency (115%), develop value-added exports, and prevent and control the red palm weevil.

Regarding green fodder, the plan is to reduce domestic production to less than one-quarter of the current demand and develop foreign investments and storage capacity. For fruit products, efforts will be made to increase the self-sufficiency rate from 25 to 40%, adopt recommendations to improve productivity, and encourage promising crops and organic cultivation. Production of red meat and poultry meat will be organized to boost productivity and reduce waste. The aim is to maintain the current self-sufficiency rate for red meat (25–30%) and increase it to at least 65% for poultry meat. Saudi Arabia also plans to increase fish production to 600 thousand metric tons from the aquaculture and fisheries sector while maintaining current self-sufficiency rates for fresh milk (122%) and eggs (115%). To achieve food security, the country has allocated 24.8 billion USD and has a plan to strengthen the agricultural sector, increase domestic production, and exports with a 25 billion USD investment in industries. Additionally, the Saudi Agricultural Development Fund offers loans worth 2 billion USD to support the agricultural sectors.

8 Conclusion and Prospects

The Saudi economy is the largest in the Middle East and North Africa region and is a member of the G20. Saudi Economy heavily relies on oil revenues. However, the Kingdom has been implementing the 2030 Vision which aims to diversify its economy by developing various strategies, plans, and programs. The aim is to include multiple sectors and sources of income, reducing the heavy reliance on oil revenues, which are greatly influenced by external factors. Additionally, the population of the Kingdom is steadily increasing and efforts are being made to provide job opportunities for Saudi citizens, with the goal of reducing dependence on foreign workers, except in cases where their expertise is required on a limited scale. They are also striving to make many professions accessible to Saudi individuals. Taking a holistic perspective, the agricultural sector in Saudi Arabia exhibits favorable prospects. The government has dedicated efforts towards developing strategies and programs to address agriculture, water, and food security, with the aim of promoting investment and adopting modern technologies to enhance production and achieve self-reliance in various food commodities. Nevertheless, the Saudi agricultural sector encounters significant challenges linked to limited water availability, climate change, and the implications of agricultural arable land, ultimately affecting the country's pursuit of food security.

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Chapter 2
Role of the Arab Organization for Agricultural Development in Promoting Agricultural Development and Food Security in the Arab Region

Ibrahim El-Dukheri and Kamel Mostafa Amer

Abstract The Arab Organization for Agricultural Development (AOAD) plays a crucial role in promoting agricultural development and ensuring food security in the Arab world. This chapter provides an in-depth analysis of the Arab Organization for Agricultural Development's (AOAD) role in promoting agricultural development and food security in the Arab region. It begins with an introduction to AOAD, its significance in the not only regional but global context as well, and the challenges it faces in the Arab region. The chapter then delves into the foundation and objectives of AOAD, its operational structure, and its key stakeholders and funding sources. An overview of agriculture in the Arab region is provided, highlighting unique practices, strengths, and challenges. The chapter further explores AOAD's strategies for agricultural development, its influence on national policies, and its contributions to sustainable farming systems. It unpacks AOAD's approach to improving food security and its achievements in this area. The chapter also discusses AOAD's efforts in promoting agricultural technologies, capacity building, and knowledge sharing. It underscores the importance of partnerships in achieving AOAD's objectives and the future of collaborative work. The chapter concludes by looking forward to the challenges and future directions for AOAD, envisioning potential internal obstacles, prospective strategies for addressing emerging issues, and opportunities for future growth and impact. The chapter emphasizes the continued relevance and importance of AOAD's mission in the Arab region.

Keywords Agricultural challenges · Agricultural development · Arab organization for agricultural development (AOAD) · Arab region · Food security · Future directions for AOAD · Internal challenges of AOAD · Vision and mission of

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AOAD · Agricultural technologies · Agricultural productivity · Arab countries · Regional cooperation

1 Introduction

1.1 Introducing the Arab Organization for Agricultural Development (AOAD)

The Arab Organization for Agricultural Development (AOAD) is a notable institution within the League of Arab States. It was established in 1970 and commenced operations in 1972 to bring about change and innovation in the field of agriculture throughout the Arab region. This organization seeks to foster growth and enhancement in the agricultural sector by means of collective action and collaboration, along with the implementation of modern techniques and practices (AOAD 2023a). The AOAD functions as a key player in consolidating the efforts of Arab States, streamlining regional objectives to invigorate agricultural development, and fortifying food security. Its commitment extends to improving the livelihoods of farming communities, instigating effective policy changes, and endorsing technological advancements in agricultural practices.

These ventures, driven by an agenda to ensure self-sufficiency and sustainability, act as testament to AOAD's commitment to a prosperous agricultural future for the Arab world. While the potential of agriculture is vast, tapping into it requires an organization like AOAD that can amalgamate various efforts into a unified direction (Devex 2023). The Organization consists of all 22 member countries of the Arab League: Algeria, Bahrain, Comoros, Djibouti, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Somalia, Sudan, Syrian Arab Republic, Tunisia, United Arab Emirates, and Yemen. Sudan hosts the organization's headquarters (Macmillan 2016). This chapter explores the Arab Organization for Agricultural Development's (AOAD) role in enhancing agricultural development and food security in the Arab region. It discusses AOAD's foundation, objectives, operational structure, and funding sources. The chapter also examines AOAD's strategies, its impact on policies, contributions to sustainable farming, and future challenges, emphasizing AOAD's ongoing relevance and significance in the region.

1.2 Agriculture and Food Security in the Arab Region

The cultivation and harvesting practices bear immense significance in the interwoven social and economic tapestry of the Arabic geopolitical area. Providing a primary source of revenue for a substantial segment of the populace, it is inherently intertwined with facets of sustenance assurance, economic equilibrium, and livelihoods. Spanning from the lush expanses of the Nile Delta to the vast date palm estates in Iraq and Saudi Arabia, the multi-faceted relevance of this sector is impossible to ignore.

Food security, a paradigm encompassing the consistent availability, access, proper use, and steadiness of food, holds a central spot in the region's concerns. Confronted with a swiftly expanding populace, the Arab zone contends with the arduous task of guaranteeing an abundant food supply. This task is rendered more intricate due to phenomena like the scarcity of water resources and climate change. In consequence, the fields of agriculture and food security are entwined threads in a complex network, casting light on the region's economic vigor, ecological endurance, and socio-political harmony (Devex 2023; Macmillan 2016). Through its roles in job creation, stimulation of rural growth, and food provision, the agricultural sector stands as an irreplaceable pillar in Arab communities.

1.3 Agricultural and Food Security Challenges in the Arab Region

Embarking on the intricate journey to address agricultural tribulations and food security fragility in the Arab region is no small task. The region is a dynamic mosaic of varied circumstances, yielding a spectrum of opportunities and disparities in agriculture and food security. The region is entrenched in an ongoing struggle with harsh environmental realities, such as diminishing water resources, persisting dryness, and declining fertility of farmable land.

Socio-economic variables, such as income disparities, political turbulence, and inadequate infrastructural assistance, further amplify these predicaments, acting as hurdles to agricultural evolution and food security sustenance. Global climate dynamics play an ominous role too, shaping the destiny of crop production and threatening the stability of the food supply.

The task at hand extends beyond the mere intensification of agricultural production. It calls for the fabrication of resilient structures that can withstand upcoming challenges. This is where the crucial role of the AOAD comes into sharp focus. The organization aims to craft comprehensive strategies that reconcile the twin objectives of agricultural advancement and food security in the Arab world.

Continuing this theme, several key challenges and potential pathways emerge (Keulertz and Mohtar 2019; FAO 2017).

a. Climate Vulnerability: The primarily arid landscape of the Arab region increases its susceptibility to the effects of climate change. Shifts in weather patterns can exacerbate desertification, soil deterioration, and water shortages, critically affecting agricultural outputs, livestock health, and ultimately food security.

b. Water Insufficiency: The region experiences some of the world's worst freshwater scarcity, negatively affecting agricultural yield and livestock. A secure water supply is crucial for food production, making this shortage a significant concern for food security.
c. Political Unrest and Conflict: The political instability and conflicts disrupting several Arab countries can have dire consequences for food availability. Wars can damage agricultural infrastructure, displace farming communities, and complicate planting and harvesting processes, leading to severe food insecurity.
d. Inadequate Investment in Agriculture: Underinvestment in the agricultural sector has led to outdated farming techniques, inefficient irrigation systems, and a technology gap. These factors contribute to a decrease in productivity and efficiency, presenting substantial challenges for food security.
e. Population Pressure and Urban Expansion: The swift population growth coupled with increased urbanization creates further strain on the food supply. The burgeoning food demand is outstripping the existing agricultural capabilities of the region.
f. Dependence on Imported Food: The region's reliance on food imports due to its arid climate and restricted agricultural capacity makes it vulnerable to the instability of global food prices and disruptions in supply chains, threatening food security.
g. Need for Stronger Governance and Collaboration: The achievement of Sustainable Development Goal 2 extends beyond food and nutrition security, calling for enhanced governance and regional cooperation. By learning from other regions' experiences, the Arab countries can work together towards eradicating hunger and malnutrition.
h. Embracing Innovation and Technology: Adopting innovative concepts like the water-energy-food nexus can help close the gap in future food demand. Harnessing technologies to improve resource efficiency and utilize the region's solar energy for desalinating water for agriculture could increase local food production.
i. Promoting Resource-Efficient Diets: Resource-efficient traditional diets in the Arab region could decrease the region's resource demand. A strategic regional framework promoting these diets can be crucial in addressing food security issues.
j. Advocating for Regional Cooperation and Technological Advancements: Regional cooperation, technological innovation, and improved governance are paramount for achieving food and nutrition security by 2030. Strengthening existing policy institutions, harmonizing subsidy regimes, and fostering public–private partnerships are necessary measures. In this context, leading nations like the UAE can play a vital role.

1.4 Significance of AOAD's Role in the Global Context

The magnitude of the AOAD influence extends far beyond mere geographical confines and acts as a pivotal component in the world's conversations about maintaining enduring agricultural practices and securing food supplies. The importance of their endeavors is multifold.

Primarily, their initiatives symbolize a united endeavor to combat agricultural difficulties in some of the globe's driest environments. In doing so, they supplement the collective global understanding and methodologies applicable to agriculture in comparable climatic circumstances. In essence, their learning is not confined to their region but has applications globally in similar arid zones.

Moving forward, the blueprints they draw for reinforcing food safety reverberate with international commitments to eradicate starvation and nutritional deficiencies, therefore standing shoulder to shoulder with the Sustainable Development Goals stipulated by the United Nations. They champion the application of revolutionary technologies, practices in agriculture that respect the environment, and strategies to build abilities, all of which substantively enrich the worldwide frames of reference for agriculture and food safety.

Additionally, the relationships that AOAD builds with a broad spectrum of international groups, NGOs, and corporate sector stakeholders reflect a cooperative model to tackle intricate global challenges. This collaborative perspective underscores the shared character of the obstacles faced and accentuates the need for a unified response. The hurdles they face are not isolated but universal, requiring a cooperative approach for meaningful resolution (AOAD 2023a).

Lastly, AOAD's work in policy advocacy, research promotion, and creating a conducive environment for agricultural development has ramifications beyond the Arab region. Their insights and experiences can inform global strategies, aiding other countries and international bodies striving to improve their agricultural sector and food security scenario.

In essence, AOAD's role serves as a lighthouse for regions grappling with similar challenges and holds immense value for global sustainable development narratives.

2 The Foundation and Objectives of AOAD

2.1 Tracing the Beginning and Growth of AOAD

The genesis of the AOAD lies in the collective aspirations of the Arab League to foster growth and resilience in the region's agricultural sector. AOAD was conceived as a specialized institution designed to coordinate agricultural development and ensure food security across the region (AOAD 2023a).

Over the years, the organization has seen considerable evolution, both in its operations and scope of activities. From setting agricultural policy guidelines to initiating various development projects, its work has expanded to cover a broad range of issues. AOAD's evolution has been marked by an increased emphasis on sustainable agricultural practices, technological adoption, and capacity building, all aimed at strengthening the agricultural sector and ensuring food security (AOAD 2023a; Devex 2023).

As it moved through decades, AOAD's journey has been one of adaptation and resilience. Despite the myriad challenges and changing dynamics of the region, the organization has remained steadfast in its commitment to its foundational goals.

2.2 *Fundamental Objectives of AOAD*

AOAD was built upon several fundamental objectives, all interconnected and collectively aiming towards a prosperous agricultural future for the Arab region. The primary goal is to increase agricultural productivity, thereby promoting economic growth and improving the quality of life for farming communities.

The dedication of AOAD to ensuring regional food security is also essential. This objective necessitates initiatives to improve access to quality food, manage supply chains efficiently, and maintain stability in food availability, even amidst global fluctuations or regional disturbances (AOAD 2023a).

Another significant objective is to promote sustainable farming practices. Given the region's environmental challenges, including water scarcity and land degradation, AOAD emphasizes the need for sustainable, resource-efficient agricultural methods.

AOAD's vision is to have an Arab agricultural sector that is competitive, sustainable, resilient, and adaptable to shocks. Such a sector would contribute to and enhance economic growth, social development, stability, rural prosperity, and food security. While its mission is to establish innovative, harmonious, competitive, and sustainable Arab agricultural sectors that bolster food and nutritional security, contribute to the eradication of poverty, and are capable of competing in regional and global markets, this can be achieved by employing climatically smart technologies, innovative methods for knowledge generation and exchange, platforms for innovation, specialized networks, and effective partnerships that facilitate a qualitative leap for the agricultural sector (AOAD 2023b).

The Economic and Social Council of the League of Arab States is recognized as the regional authority that governs the organization. The organizational structure is comprised of the General Assembly, the Executive Board, the General Administration, the four regional offices (East Region, West Region, Middle Region, and Arabian Peninsula Region), the specialized offices, and the Arab Technical Institute for Agriculture and Fisheries. The General Assembly includes all ministers responsible for agriculture and fisheries in the 22 Arab countries (Macmillan 2016).

AOAD's organizational structure has been designed to facilitate its diverse range of activities and achieve its ambitious objectives. The General Assembly is responsible for setting broad strategic directions and approving the budget and work plan. While the Executive Board, composed of selected member state representatives (ministers), operates under the General Assembly, and is charged with implementing the approved plans.

2.3 The Working Structure: A Detailed Look at AOAD Operations

AOAD's daily operations are managed by the General Secretariat, led by a Director-General. This entity coordinates the various activities, manages relationships with member states and partners, and monitors progress towards the organization's objectives.

This structure, coupled with AOAD's commitment to collaboration and transparency, allows the organization to work efficiently and effectively towards its goals of agricultural development and food security (AOAD 2023a).

Over the past five decades, the organization has endeavored to bolster and foster cooperation and integration among Arab countries in sectors within its purview. It has engaged with numerous economic, social, political, and environmental changes on the Arab, regional, and international levels. It has prepared its annual plans and programs in response to these changes and in accordance with the needs and requirements of its member states. The organization has focused on prioritized issues—both Arab and global—throughout various stages of its operation, ensuring continuity in achieving its general and specific objectives, building on what has been accomplished at each stage, and developing and adapting it to meet the needs of the subsequent stage.

2.4 An Overview of Key Stakeholders and Funding Sources for AOAD

The functionality and initiatives of AOAD are fueled and sustained by a tangled network of stakeholders and diverse financing routes. A cluster of entities, referred to as "stakeholders," significantly shapes the organization's operational landscape. This set of participants bifurcates into two distinct segments: those intrinsically woven into the organization's fabric (internal stakeholders) and those that exert influence from an external vantage point (external stakeholders).

Internal stakeholders are essentially the member states constituting the General Assembly of AOAD. Through their ministries of agriculture, these nations wield substantial control over the direction of AOAD's initiatives, shaping them to mirror national objectives.

External stakeholders, on the other hand, comprise international entities, non-governmental organizations (NGOs), and private-sector organizations. These players, especially international development bodies, have significant partnerships with AOAD. Such collaborations infuse AOAD with international insights and best practices, strengthening its ability to fulfill its mission (Penta 2023). To carry out its duties, AOAD leans on a variety of funding avenues, including membership fees, donor support, and alliances that often come with financial backing.

The contribution of member states is a key pillar of AOAD's budget. Each nation within the Arab League chipped in towards the AOAD budget as per a pre-set scale. These payments form a crucial chunk of AOAD's operational finances, underwriting a range of projects and initiatives dedicated to agricultural advancement in the Arab world. In addition to regular budgetary inputs from its members, AOAD also garners substantial financial aid from other nations and global donor entities that have a vested interest in fostering agricultural progress in the region. These endowments typically finance specific initiatives, like enhancing irrigation systems or promoting sustainable farming techniques.

Moreover, AOAD's partnerships with international bodies, NGOs, or private-sector organizations often carry financial benefits. Such alliances might bring in direct monetary support or contribute indirectly through in-kind support, like the provision of machinery or specialized knowledge (AOAD 2023c).

The engagement of farming communities at the grass-roots level is essential for AOAD's functioning. The specific needs and challenges that these communities face are the propelling force that fuels AOAD's strategies and schemes. More importantly, their proactive participation ensures that these programs are culturally appropriate and effective.

3 An Overview of Agriculture in the Arab Region

3.1 A Country-Wise Overview of the Agricultural Sector

Within the Arab realm, an intricate tapestry of farming environments unfolds, with each nation boasting its own distinct compilation of wealth, tribulations, and agricultural methods. The fertility of the Nile River endows nations like Egypt and Sudan with the capacity to yield an extensive assortment of crops such as wheat, corn, and cotton. In stark contrast, Arabian Peninsula nations, including Saudi Arabia and the United Arab Emirates, are forced, due to their harsh desert surroundings, to heavily depend on advanced irrigation systems to maintain their farming industries.

Countries blessed with more moderate weather conditions, like Lebanon and Syria, are celebrated for their lush fruit orchards and vineyards. Conversely, the countries constituting the Maghreb region, particularly Morocco, Algeria, and Tunisia, have made their mark as substantial providers of olives, citrus fruits, and grains. Further, nations like Yemen and Oman, despite being situated in demanding landscapes, have succeeded in nurturing distinct crops like coffee and frankincense (AOAD 2023d).

This panoramic perspective of the Arab region's farming heterogeneity sets the stage for an opportunity to harness mutual collaboration and share knowledge, contributing to a shared agricultural wealth.

3.2 Highlighting Unique Agricultural Practices and Strengths in the Region

Agriculture in the Arab region presents a fascinating subject, a mosaic of unique practices and strengths that stand in testament to the resilience and creativity of its people. Across the swathes of this diverse region, from the fertile banks of the Nile to the arid landscapes of the Arabian Peninsula, distinct methods and approaches shape the agricultural narrative, weaving a tapestry rich with ingenuity and adaptability.

An outstanding feature of Arab agricultural practices is the ancient, yet highly effective, method of irrigation called "falaj". Predominantly used in Oman, this system ingeniously channels water from underground sources or mountain springs to farms, even across considerable distances. The sustainable nature of this system and its minimal reliance on modern technology demonstrate a deep understanding of the environment and resource management.

A salient feature of agricultural practice in the Arab region is the growth of date palms. These resilient, drought-resistant trees not only offer a nourishing source of food, but they also considerably contribute to the cultural and economic dynamics of the region. The aptitude of the date palm to survive in arid conditions highlights the robustness of Arab farming practices in exploiting the potential of its inhospitable surroundings.

Further, the Arab region has made considerable advancements in harnessing cutting-edge agricultural technology. Techniques such as hydroponics and vertical farming are applied in metropolitan hubs like Dubai and Abu Dhabi in the United Arab Emirates to tackle the scarcity of fertile land and water resources. These techniques underline the region's flexibility and readiness to integrate innovative technologies within its farming environment.

Agroforestry, a practice that combines forestry and agriculture to create integrated and sustainable land-use systems, is another strength of Arab agriculture. Morocco's argan tree cultivation offers a vivid illustration of this. The argan tree, remarkably resilient and well-adapted to arid conditions, offers multiple benefits, including edible oil, cosmetic products, and soil conservation. This traditional practice indicates a robust sense of sustainable farming and biodiversity conservation.

On the macro level, the Arab region has made significant progress in agricultural policy formulation. The Arab Organization for Agricultural Development (AOAD) works towards the development of a cohesive agricultural strategy for the region, emphasizing sustainability, food security, and rural development. The existence of such a body underscores the importance placed on agriculture in the Arab region's economic and societal structures.

The Arab region's agriculture sector showcases a blend of traditional wisdom, modern innovation, and a unique understanding of its diverse landscapes. By leveraging their unique strengths and embracing future-facing agricultural practices, the Arab world holds a significant role in shaping the future of global agriculture.

Additionally, the region is globally recognized for certain agricultural products. Dates from Saudi Arabia, olive oil from Tunisia, and Moroccan argan oil are just a few examples of the region's agricultural strengths that have garnered international acclaim.

These practices and products not only underline the region's agricultural diversity but also underscore the potential for adding value through innovative processing and marketing strategies.

3.3 Navigating Through Challenges

The Arab domain, albeit adorned with unique virtues, contends with a plenitude of trials that form formidable barricades to the enhancement of agriculture and the fortification of food security. Climate change stands out as a severe concern. As the mercury rises, the recurrence of dry spells escalates, and rainfall exhibits volatility, there's a potential disturbance in the harmony of agricultural yields and the rhythm of farming sequences.

Water scarcity further compounds the complexity of the situation. The Arab realm is counted among the most parched corners of the world, with the per capita allotment of water falling drastically short of the global mean. This dearth is magnified by demographic expansion, the swelling of urban areas, and the unchecked extraction of subterranean water assets.

The erosion of fertile terrain, frequently a consequence of non-sustainable agrarian methods, represents another monumental impediment. This predicament, along with the scarce supply of tillable soil, limits the region's agricultural prospects.

Not to forget, there is a tangle of socio-economic elements at work. A host of Arab nations find themselves wrestling with the specters of political volatility, inflated rates of joblessness, and wealth disparities. These components might deter investment in agriculture, influence the cost of food, and put a strain on the common individual's capacity to procure nutritious sustenance (AOAD 2023b).

3.4 The Relationship Between Agriculture and Food Security

The nexus between farming practices and sustenance availability within the Arab territories comprises an intricate amalgamation of diverse elements, including climatic aspects, water provision, socio-economic context, and regulatory schema. The agricultural sector forms the lifeline for food security, offering the main avenue for food cultivation. Nevertheless, this region grapples with formidable impediments like water scarcity, climate change, land degradation, and socio-economic context, all of which potentially impact farming yield and subsequently food security (Alzadjali 2017).

Agricultural pursuits in the Arab territories display a rich diversity and differ from one nation to another, dictated by factors like climate, topography, and resource availability. Countries like Egypt and Sudan assign a sizable segment of their land mass for agricultural endeavors, while others like Saudi Arabia and the United Arab Emirates, due to their arid circumstances, have a scant amount of land available for cultivation. Yet, despite such variations, agriculture continues to be an influential part of the region, fostering employment opportunities, bolstering the economy, and ensuring sustenance stability.

The concept of food security, as outlined by the Food and Agriculture Organization (FAO), compresses a scenario where every individual, without exception, can physically and financially access ample, safe, and nutrient-rich food that fulfills their specific dietary necessities and preferred food choices, enabling them to lead a vigorous and healthful existence (FAO 1996). However, actualizing this concept of food security in Arab regions is a formidable challenge due to a host of factors. These include an ever-growing population, unpredictable political situations, and environmental hurdles like the shortage of water and changes in climate conditions.

The Arab Organization for Agricultural Development (AOAD) is instrumental in advocating agricultural growth and boosting food security within the Arab territories. One of AOAD's pivotal strategies is "the Arab Strategy for Sustainable Agricultural Development (2020–2030)" coupled with the "Arab Program for the Sustainability of Food Security," both of which target the predicaments impeding the agricultural industry and food security within the region (AOAD 2023b, e).

AOAD's agenda incorporates the endorsement of sustainable farming techniques, augmentation of water management, enhancement of technological utilization in farming, and capacity building via educational and training programs. As an illustration, AOAD hosted a training session on the application of prediction models and geographic information systems to approximate crop yield. Such initiatives aid in enhancing farming output, advocating sustainable resource utilization, and ultimately fortifying food security within the region.

Moreover, AOAD engages in cooperative endeavors with global entities like FAO, to confront the complexities of food availability. For example, a symposium facilitated collectively by AOAD and FAO focused on the discourse of regional policies pertinent to solar-powered irrigation systems, highlighting the vital nature of inventive solutions to tackle the issue of water scarcity, a major obstacle impacting agriculture in the region.

4 AOAD's Role in Advancing Agriculture

4.1 The Path to Growth: AOAD's Strategies for Agricultural Development

With an ambitious vision to revolutionize the agricultural landscape in the Arab region, AOAD is fueling an agricultural renaissance through the inception of numerous advanced methodologies. These methods emphasize the enhancement of crop output, the adoption of eco-friendly farming techniques, and fortifying collaborations across the region.

A critical venture on their agenda includes boosting crop production through the integration of superior seed types, cutting-edge agricultural methods, and water-efficient irrigation mechanisms. AOAD also advocates for the utilization of sustainable farming methodologies such as organic farming, agroforestry, and preservation farming to secure the agricultural sector's long-term resilience.

An exemplification of the effectiveness of these strategies can be seen in Sudan, where AOAD's interventions have been transformative. The region was grappling with deteriorating soil fertility and dwindling water resources when AOAD intervened with preservation farming methodologies and water-efficient irrigation systems in select areas. These endeavors not only manifested in an enhancement of agricultural productivities, but simultaneously they invigorated the vitality of the soil and instigated conservation of our precious resource, water. This thereby fosters an enduring viability for cultivation within these regions.

Amid it all, the expansive ambitions embedded in the Sustainable Arab Agricultural Development Strategy 2020–2030 serve as a comprehensive guide to address the myriad of issues that the agricultural industry in the Arab world is currently confronting. This strategy outlines these enduring strategic objectives, as detailed below:

The First Milestone: Advocating and aiding transformations in agricultural and food systems to abolish hunger and alleviate poverty.

The second milestone: Ensuring the effective stewardship of agricultural resources and ecological systems, thereby securing their long-term viability in the Arab region.

The Third Milestone: Bolstering the Integration of Arab Agriculture and Establishing Procedures, Policies, and Systems for Arab Agricultural Trade and Investment.

The Fourth Milestone: Nurturing and propagating rural Arab prosperity, thereby equipping them with the ability to adapt to environmental, economic, and societal shifts pertaining to the agricultural sector.

The Fifth Milestone: Administering, engaging, and providing technical and institutional agricultural knowledge to assist policy decision-making (AOAD 2023b).

To realize these objectives, AOAD orchestrates a slew of ground-breaking national and international projects, fortifies human and institutional capacities, generates comprehensive studies, reports, and statistics, and offers technical consultations and emergency financial aid. Additionally, the organization hosts conferences, seminars, and workshops, tracks regional and global trends, and evaluates their implications for Arab agriculture as part of its comprehensive approach.

4.2 AOAD's Influence on National Agricultural Policies

AOAD has significantly shaped agricultural strategies within the Arab world, with its influence rippling across multiple dimensions, including sustainable agriculture promotion and market structure enhancement. In particular, the AOAD's advocacy for sustainable farming techniques is undeniably noticeable. As an illustration, the organization has championed the water-energy-food NEXUS approach to help alleviate climate change repercussions, thus aligning with the global trajectory that underscores the necessity of agriculture's sustainable intensification, thereby morphing it from a carbon contributor to a carbon absorber (Russell and Kumar (2017).

The AOAD's knowledge on sustainable agriculture and climate change adaptation has sparked the integration of these aspects into several Arab nations' agricultural guidelines. This integration has fortified the agricultural sector's resilience in these nations, hence fortifying food security.

In tandem with encouraging sustainable agriculture, the AOAD has been instrumental in molding policies concerning agricultural commerce. Grasping the vital role trade plays in agricultural development, the AOAD has endeavored to encourage policies that smooth the process of agricultural product trade. This has encompassed initiatives to diminish trade obstructions and foster regional integration, subsequently widening the market for Arab farmers.

The AOAD's impact on national agricultural strategies surpasses just the advocacy of sustainable procedures and trade. The organization has also participated in endeavors to bolster food security in the Arab region. This participation has necessitated the formulation of strategies aiming to augment agricultural productivity and facilitate food accessibility. Given the complications brought about by elements like climate change and population expansion, the AOAD's efforts in this regard have been especially crucial.

A specific instance that elucidates the AOAD's impact on national agricultural strategies is its promotion of technological integration within agriculture. The AOAD has fervently endorsed the uptake of contemporary technologies like drone utilization in farming, artificial intelligence, and machine learning in crop cultivation. This endorsement has not merely elevated productivity but has also support the agricultural sector's resilience to destabilizing factors such as climate change (AOAD 2023e).

4.3 Working Towards a Sustainable Future: AOAD's Contribution to Green Farming and Tackling Climate Change

In the complex ballet of agriculture, environmental guardianship, and the ceaseless flux of climate, the AOAD has launched an array of programs. These programs will help it to achieve its mission, which is to champion environmentally considerate farming techniques.

Sustainable agriculture, often known as "eco-friendly farming," aims to meet today's food and textile needs without compromising future generations. This modality encourages farming techniques that are not only profitable and environmentally friendly but also advantageous to communities. The AOAD's strategy towards sustainable agriculture is multi-pronged, employing a spectrum of tactics from advocating for organic farming to promoting the use of renewable energy in farming operations.

The AOAD promotes organic farming. This agricultural method avoids pesticides, fertilizers, GMOs, antibiotics, and growth hormones. It improves agricultural ecosystem, soil organisms, plants, and livestock. Organic farming promotes eco-friendly, sustainable businesses (FAO 2023a).

The AOAD also aggressively promotes renewable energy in farming. It supports the use of different types of renewable energies because they can reduce the agricultural sector's dependence on fossil fuels. The AOAD has helped Arab nations develop solar-powered irrigation systems, lowering their carbon footprint.

Climate change threatens Arab agriculture and food security. Rising temperatures, changing rainfall patterns, and more extreme weather events can impact crop output. The AOAD is driving agricultural climate resilience. To help farmers adapt to climate change, it has been developing and promoting climate-smart agricultural practices like drought-resistant crop varieties and enhanced irrigation (FAO 2023b).

Moreover, AOAD has been actively participating in policy advocacy to tackle climate change. It has been collaborating with governments in the Arab region to formulate and execute policies that encourage sustainable agriculture and climate change mitigation. AOAD's policy advocacy initiatives have led to several Arab countries integrating climate change mitigation and adaptation strategies into their national agricultural policies.

AOAD's efforts in endorsing eco-friendly farming and addressing climate change have been substantial and widespread. Through its diverse initiatives and programs, AOAD has shown a robust commitment to ensuring the sustainability of the agricultural sector and improving food security in the Arab region amidst climate change.

5 AOAD's Approach and Achievements in Food Security

5.1 Elements and Significance of Food Security

Food availability is misunderstood. It encompasses more variables essential to human and social life. FAO stated that "food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 1996). This widely accepted definition points to the following dimensions of food security: availability, access, utilization, and stability. Food insecurity can result from any deficit.

The physical presence of food depends on food production, stock levels, and net commerce. To meet a population's nutritional demands, food must be constantly available in appropriate quantities.

Food access is the second dimension. This is affected by socioeconomic factors like income, food prices, and social safety nets. Food availability does not ensure access; economic and societal constraints might hinder people from getting the food they need.

The third dimension, utilization, is the body's ability to digest and metabolize food. This depends on dietary understanding, health, and water and sanitation quality. Malnutrition can occur even if food is available and accessible due to a poor diet or illness.

The final dimension, stability, emphasizes food availability, access, and use. Food security can be disrupted by seasonal, annual, or unexpected shocks (FAO 2023c).

The importance of food security is immense. Physical health, cognitive growth, and overall well-being depend on it. Social stability and economic productivity depend on it. Malnutrition, delayed child growth, social unrest, and economic loss can result from food insecurity.

5.2 AOAD's Approaches to Improving Food Security

The AOAD takes an active role in enhancing food security in the Arab region through a multidimensional approach. AOAD implements strategic initiatives and collaborates with various stakeholders to address the complex challenges related to food security and promote sustainable agricultural practices. This sub-chapter delves into AOAD's approach to improving food security, highlighting its key strategies and initiatives AOAD (2023b).

a. Conducting Comprehensive Data Collection, Analysis and Assessment:

The AOAD recognizes the significance of accurate and up-to-date data in understanding food security dynamics. By conducting comprehensive data collection, analysis and assessment, AOAD aims to identify vulnerabilities and gaps in the food systems of the Arab region. This involves examining factors such as agricultural production, supply chains, trade patterns, and consumption trends. Through a comprehensive understanding of the region's food security landscape, AOAD can develop targeted interventions to address specific challenges.

b. Strengthening Local Food Production:

AOAD's primary strategy for improving food security is to enhance local food production capacities. The organization closely collaborates with member countries to identify and promote sustainable agricultural practices that optimize productivity while minimizing environmental impact. This includes providing technical assistance, training programs, and access to improved seeds, fertilizers, and other agricultural inputs. By empowering local farmers and promoting best practices, AOAD aims to increase agricultural productivity and reduce dependence on food imports.

c. Diversifying Food Sources and Supply Chains:

AOAD fervently recognizes the critical significance of diversifying food sources and supply chains to ensure unfaltering food security in the long run. The organization actively urges member countries to embark on an adventurous journey of exploring alternative agricultural production systems, delving into the realms of aquaculture, vertical farming, and agroforestry as promising avenues to broaden the spectrum of accessible food resources. Furthermore, AOAD tenaciously takes the reins in facilitating regional cooperation and forging trade agreements that seamlessly facilitate the seamless movement of agricultural products across borders. These bold initiatives ardently combat the menacing specter of supply chain disruptions, ultimately culminating in the establishment of a steadfast and unwavering food supply within the region.

d. Enhancing Post-Harvest Management and Storage:

In its unwavering commitment to food security, AOAD places significant emphasis on enhancing post-harvest management and storage systems to combat the substantial threat of post-harvest losses. AOAD actively advocates for the development of efficient infrastructure, including storage facilities, cold chains, and processing centers. These strategic investments play a pivotal role in minimizing spoilage and preserving the nutritional value of harvested crops. By tackling post-harvest challenges head-on, AOAD significantly contributes to the reduction of food waste and the overall improvement of food security across the Arab region.

e. Promoting Social Safety Nets and Nutrition Programs:

AOAD firmly recognizes the intricate relationship between food security, poverty alleviation, and nutrition. The organization consistently and in collaboration with international organization such as the United Nations World food program (WFP), champions the establishment of robust social safety nets and nutrition programs to ensure that vulnerable populations have consistent access to sufficient and nutritious food. This encompasses various initiatives, such as implementing cash transfer programs, facilitating school feeding programs, and launching comprehensive nutrition education campaigns. By addressing the underlying socio-economic factors that perpetuate food insecurity, AOAD actively endeavors to foster resilient communities and enhance overall well-being throughout the Arab region.

f. Collaborating with International Partners:

AOAD actively engages in collaborative efforts with international partners, including other regional organizations, NGOs, and international agencies, to amplify its effectiveness in addressing food security challenges. By leveraging these partnerships, AOAD facilitates the invaluable exchange of knowledge, expertise, and resources, leading to the development of innovative solutions and the identification of best practices. Through these concerted endeavors, AOAD expands its reach and impact, promoting a coordinated and comprehensive approach to food security not only within the Arab region but also on a global scale.

g. Boosting Irrigation and Water Management:

Water scarcity being a prevalent challenge, AOAD prioritizes initiatives that enhance irrigation and water management practices. The organization actively promotes the adoption of efficient irrigation techniques, such as drip irrigation and precision agriculture, to optimize water usage and minimize waste. AOAD also lends support to the development of water storage and harvesting systems, along with implementing water conservation measures, aiming to secure sustainable water resources for agricultural purposes.

h. Championing Regenerative and Sustainable Farming:

For long-term food security, AOAD supports sustainable farming. The organization promotes regenerative principles that incorporate ecological processes into agricultural systems. AOAD supports organic farming, agroforestry, and integrated pest management to promote soil health, maintain biodiversity, and build climate change resilience for sustainable food production systems.

i. Strengthening Agricultural Research and Innovation:

AOAD prioritizes agricultural research and innovation for food security. The organization actively supports research on crop varieties, resilient farming methods, and new solutions to agricultural issues. AOAD encourages research organizations, universities, and farmers to share knowledge and advanced technology. AOAD promotes food security and sustainability via agricultural research and innovation.

j. Empowering Women and Involving Youth in Agriculture:

Recognizing the demographic shift and the need to engage women and youth in agriculture, AOAD implements programs aimed at promoting youth involvement and women empowerment in the sector. The organization actively supports initiatives that provide vocational training, entrepreneurship opportunities, and access to financing for young farmers. AOAD also champions the adoption of modern technologies and digital tools to attract and empower young farmers, ensuring the sector's sustainability and continuity. By investing in women and youth, AOAD not only contributes to food security but also fosters a vibrant and resilient agricultural sector.

5.3 AOAD's Work Progress in Improving Food Security

Over the course of the preceding five decades, the organization has exerted substantive efforts in areas of agricultural development, food security, and assisting member countries in the advancement and progression of their agricultural, livestock, and fishery sectors. Notably, it has left its mark on the coordination and activation of Arab developmental work in all agricultural fields, with its journey over these decades adorned with numerous significant achievements in plant, animal, and fishery wealth sectors as well as food security, among which, for instance, are:

In the area of strengthening cooperation with Arab, regional, and international organizations, and the private sector (AOAD 2023f):

1. Signing of approximately 225 agreements and memoranda of understanding with most organizations, bodies, as well as financing funds at the Arab, regional, and international levels.

In the fields of the organization's work as an Arab center of expertise in agricultural and fishery sectors AOAD (2023g): the organization's role as an Arab center of expertise in agricultural sectors includes preparing and implementing technical and financial feasibility studies for agricultural development projects or overseeing their implementation, in addition to preparing and implementing specialized training courses for Arab and African agricultural cadres. In this field, the following was accomplished:

a. Execution of 73 contractual studies;
b. Implementation of 86 contractual projects;
c. Preparation and implementation of approximately 42 training courses for the benefit of Arab and African countries.

In the realm of studies and consultations (AOAD 2023h):

a. accomplishment of ~ 820 national and regional studies;
b. provision of over 500 scientific and technical consultations to member states.

In the domain of project implementation AOAD (2023i):

2. Implementation of more than 1320 pioneering developmental projects, distributed between regional, national, and joint projects that cover all plant, animal, and fishery sectors.

In the sphere of plans and strategies:

a. preparation and issuance of the Arab Agricultural Development Strategy Document (1982);

b. preparation and supervision of the execution of the Sustainable Arab Agricultural Development Strategy for the upcoming two decades, 2005–2025, which was approved by the Riyadh Summit in 2007 as part of the joint strategy for Arab economic and social work; the launching of the Riyadh Declaration to enhance Arab cooperation in the face of the global food crisis (2008);
c. unveiling the Riyadh Declaration to strengthen Arab cooperation to combat the global food crisis (2008);
d. creation of the Arab Food Program Document;
e. the establishment of the Emergency Program for Arab Food Security, which was launched by the Economic and Social Development Summit held in Kuwait (2009) and the monitoring of its implementation;
f. creation of a study on the establishment of an Arab mechanism for financing agricultural development and Arab food security (2012);
g. formulation and release of the Arab Strategy for Aquaculture, 2018–2037;
h. the Arab agreement for the exchange of plant genetic resources and its heritage knowledge and the division of benefits arising from its use;
i. preparation and approval of the Sustainable Arab Agricultural Development Strategy, 2020–2030, at Algeria Summit, 2022;
j. formulation and issuance of the Arab Strategy for Sustainable Management of Pastoral Resources 2020–2040—at Algeria Summit 2022;
k. formulation and issuance of the Arab Program for Sustaining Food Security—at Algeria Summit 2022.

In the domain of reports and statistics:

a. publication of 40 editions of the Annual Arab Agricultural Statistics Book;
b. release of 13 editions of the Annual Arab Fisheries Statistics Book;
c. dissemination of 32 instances of the Arab Food Security Status Report.

In the area of training and capacity building (AOAD 2023j):

a. holding of 176 national training courses covering all agricultural fields, benefiting around 4400 cadres from the Arab agricultural ministries' staff;
b. execution of 1211 regional training courses, benefiting ~ 28,638 cadres from the Arab agricultural ministries' staff;
c. graduation of around 1700 students from the Arab Technical Institute for Agriculture and Fisheries (formerly the Arab Institute for Forests and Pastures) after they obtained a 2-year diploma in forestry, pastures, biodiversity, and environment.

In the field of networks and databases:

a. the Arab Network for Genetic Resources of Food and Agriculture Animals;
b. the Arab Network for Plant Genetic Resources;
c. the Arab Agricultural Marketing Information Network;
d. the Arab Network for Rural, Bedouin, and Coastal Women;
e. the Arab Network for Aquaculture;
f. the Arab Network for Sustainable Management of Pastoral Resources;
g. the Arab Network for Promotion of Honeybee Breeding.

h. The Arab Network for Animal Health;
i. the Arab Agricultural and Fishery Research and Innovation Network for Technology Transfer;
j. the Arab Agricultural Statistical Database;
k. the Expert System for diagnosing Rift Valley fever, Brucellosis, and Foot and mouth disease;
l. the Arab Agricultural Experts Database;
m. the Arab Statistical Database, and
n. the Electronic System for Collecting and Publishing Arab Agricultural Data.

6 From Barriers to Breakthroughs: AOAD's Journey in Promoting Agricultural Technologies, Capacity Building and Knowledge Sharing

6.1 Overcoming Barriers: AOAD's Plans to Address Challenges Through Capacity Building

AOAD has identified and addressed the impediments to the adoption of agricultural innovations, such as a limited comprehension of new technologies, scarce technological resources, substandard infrastructure, and a significant skills gap.

In response, AOAD has formulated a holistic strategy that emphasizes policy transformation, capacity enhancement, and the endorsement of groundbreaking technologies. Recognizing that obsolete policies can obstruct the integration of new technologies, AOAD proactively collaborates with regional governments to advocate for policy modifications. This involves engaging in high-level dialogues with policymakers and submitting detailed policy recommendations substantiated by comprehensive research.

To address the skills gap, AOAD has launched a variety of training initiatives aimed at arming agricultural workers with the necessary skills and knowledge to utilize new technologies. These programs encompass a broad range of topics, from operating modern farming equipment to more complex subjects such as precision agriculture and sustainable farming practices (AOAD 2023e).

The Arab Technical Institute for Agriculture and Fisheries, situated in Lattakia, Syrian Arab Republic, exemplifies AOAD's commitment to education and capacity building. The institute offers diplomas in fields crucial to the region's agricultural development, such as forests, pastures, the environment, and biodiversity. These specialized programs equip students with a profound understanding of these areas, enabling them to contribute to sustainable agricultural practices and environmental conservation in the region (AOAD 2023j).

In the realm of capacity augmentation, AOAD places significant emphasis on practical training. Acknowledging the indispensable role of experiential learning in the agricultural domain, AOAD orchestrates training avenues that enable participants to implement their acquired knowledge in tangible scenarios. This methodology not only bolsters the practical competencies of the trainees but also imparts a profound comprehension of the agricultural sector's intricacies and challenges.

Moreover, AOAD has made substantial progress in endorsing innovative technologies within the agricultural sphere. This encompasses the direct allocation of technology to farmers and the creation of demonstration farms. By facilitating farmers' witnessing the advantages of these technologies firsthand, AOAD has markedly amplified their adoption (AOAD 2023b).

Through the amalgamation of policy reform, capacity augmentation, and the endorsement of innovative technologies, AOAD has triumphed in surmounting numerous barriers to technology assimilation. However, this is an ongoing process, and much work remains to guarantee that all farmers in the region benefit from agricultural technology advances. AOAD is strengthening the Arab region's agricultural workforce to adopt new technology and practices, improving food security and development.

6.2 Driving Innovation: AOAD's Efforts in Promoting Agricultural Technologies

AOAD has emerged as a beacon of innovation in the agricultural landscape of the Arab region. This has been realized through a multi-dimensional strategy that encompasses the endorsement of state-of-the-art agricultural technologies, the cultivation of a fertile environment for their assimilation, and the facilitation of knowledge exchange among stakeholders.

AOAD has promoted agricultural technologies extensively. Precision agriculture—observing, measuring, and responding to crop variability—has been a major focus. AOAD has promoted precision agriculture using GPS, GIS, and remote sensing through various projects and collaborations. These technologies help farmers maximize input returns while saving resources and improving productivity and sustainability (AOAD 2023a; Devex 2023).

AOAD has supported the use of GMOs to increase food yields and fight pests and illnesses in biotechnology. In the Arab region, harsh weather and water scarcity make agriculture difficult. AOAD has strengthened agricultural resilience by promoting drought-resistant and salt-tolerant crop cultivars.

ICT can revolutionize agriculture, according to AOAD. It marketed mobile apps for agricultural information, weather updates, and market access. It also supports blockchain technology to improve agricultural supply chain traceability and transparency.

Promoting agricultural innovations is difficult. Awareness, infrastructure, and regulations can hinder their absorption. Advocacy, capacity building, and policy discourse have helped AOAD address these issues. It has worked with governments to build enabling policies, trained farmers and extension workers, and promoted the benefits of these technologies (AOAD 2023a; Devex 2023).

6.3 AOAD's Initiatives for Sharing Knowledge and Promoting Research:

The AOAD has been active in encouraging a culture of knowledge sharing and promoting the use of research results within the agricultural sector of the Arab region. This has been achieved through a variety of initiatives aimed at enhancing capacity building, skills enhancement, and innovation.

One of the key initiatives of AOAD is the establishment of a knowledge hub to assist decision-makers. This platform serves as a repository of information, data and research related to agricultural practices, food security, and sustainable farming. It provides access to a wealth of resources, including collected and analyzed data, research papers, policy recommendations, and technical advice, thereby enabling policymakers and practitioners to make informed decisions (AOAD 2023b).

The knowledge hub also plays a crucial role in promoting a culture of knowledge sharing. By providing a platform for the exchange of ideas and information, it fosters collaboration and encourages the dissemination of best practices within the agricultural sector. This, in turn, contributes to capacity building and skills enhancement, as individuals and organizations can learn from each other's experiences and insights (Castro et al. 2019).

In addition to the knowledge hub, AOAD also promotes research through the annual Prize of the Organization and the scientific hackathons that it sponsors. These initiatives encourage researchers to contribute to the body of knowledge in the fields of agriculture and food security. By recognizing and rewarding outstanding research, AOAD not only fosters innovation but also helps raise the profile of these critical issues.

AOAD's commitment to promoting research and knowledge sharing extends to its organization of workshops, seminars, hackathons, and training programs. These events provide opportunities for individuals and organizations to enhance their skills, learn about the latest developments in the field, and network with other professionals. They also serve as a platform for the dissemination of research findings and practical applications, thereby bridging the gap between research and practice.

Furthermore, AOAD provides funding and technical support for research and development initiatives. This support enables researchers to undertake projects that might otherwise be beyond their means, thereby fostering innovation and contributing to the advancement of the agricultural sector.

In the face of challenges such as climate change, the role of research and knowledge sharing in promoting sustainable farming practices and enhancing food security cannot be overstated. Through its various initiatives, AOAD is playing a crucial role in fostering a culture of knowledge sharing and promoting research within the agricultural sector. These efforts are not only enhancing capacity building and skills enhancement but are also contributing to the development of innovative solutions to the challenges facing the sector.

7 The Strength of Partnerships: AOAD's Collaborative Work

7.1 The Role of Partnerships in Achieving AOAD's Objectives

A fundamental methodology for realizing the objectives of the AOAD is the development of strategic collaborations with a wide range of institutions, encompassing NGOs, corporate organizations, regional bodies, and global organizations. These partnerships are vital conduits for the exchange of knowledge, fostering capacity, and mobilizing resources, all of which are integral to enduring agricultural growth (AOAD 2023a).

The Arab Strategy for Sustainable Agricultural Development (2020–2030) shapes the alliances that AOAD forms, emphasizing the critical role of sustainable farming, and innovation, for attaining food security. It is congruent with the overarching Sustainable Development Goals (SDGs), especially SDG 17, which underscores the pivotal role of collaboration in attaining these objectives.

AOAD establishes a wide array of collaborations, extending from grassroots, community-driven initiatives to extensive development projects. For example, collaborations with NGOs primarily target community-centric programs, exploiting their local expertise and connections to enhance sustainable agricultural methods and value chains at the community level. Conversely, collaborations with corporate organizations often incorporate the adoption of advanced technology and innovative practices to boost agricultural productivity and durability.

As an example, the Food and Agriculture Organization (FAO), the Economic and Social Commission for Western Asia (ESCWA), the World Food Program (WFP), and the Islamic Development Bank (IsDB) help the AOAD achieve its goals. Farmers and other agricultural stakeholders benefit from capacity-building measures, including training programs and knowledge dissemination platforms, in this cooperation.

AOAD's regional operating scale presents a clear advantage against the global scale of international partners, notably the UN entities, in terms of coordinating and harmonizing efforts across diverse countries in the Arab region and various sectors within each country. AOAD, acting as a centralized node, ensures alignment and complementarity among the efforts of different partners, thereby optimizing their collective influence.

Policy advocacy forms another vital element of AOAD's collaborations. By closely cooperating with policymakers and other key players, AOAD can shape the formation and execution of policies bolstering sustainable agricultural growth and food security. This includes policies related to commerce, investment, research, development, and environmental safeguarding (AOAD 2023d).

Partnerships are instrumental in AOAD's pursuit to foster agricultural growth and food security in the Arab region. Through strategic alliances with NGOs, corporate entities, and global organizations, AOAD can harness a broad array of resources and expertise to accomplish its goals. These collaborations not only augment AOAD's capacity but also significantly contribute to the overarching aim of sustainable development in the Arab region.

7.2 *The Future of Collaborative Work: Expanding Partnerships and Navigating Challenges*

The organization's long-term success depends on strengthening these connections and navigating related difficulties. The future of joint endeavors within AOAD will likely see an augmentation of alliances across an expanded spectrum of sectors and geographical territories. This augmentation will be impelled by the escalating intricacy of the predicaments impinging on agricultural development and food security in the Arab region. Global predicaments such as climate change, population expansion, and economic instability demand global resolutions. Therefore, AOAD will need to form alliances with a diverse assortment of entities, from international organizations and governments to private sector corporations and civil society groups (Smyth et al. 2021).

In the future, AOAD will be extending its strategic alliances under the protection of the League of Arab States and towards territories such as China, Africa, India, and Latin America. These new alliances will introduce a plethora of resources, expertise, and networks that can bolster AOAD's capability to confront the challenges of agricultural development and food security.

However, the augmentation of alliances will not be devoid of challenges. Making sure these alliances benefit everyone and support their strategic goals will be a major task. This will call for meticulous negotiation and the establishment of explicit roles and responsibilities for each ally. It will also necessitate ongoing communication and transparency to ensure that all allies are aligned and working towards the same ambitions.

Another challenge will be managing the intricacy of these alliances. As alliances expand to include more entities and cover an expanded range of issues, they will inevitably become more intricate. This will require AOAD to cultivate new skills and capabilities in areas such as alliance management, stakeholder engagement, and conflict resolution. It will also require the organization to invest in systems and processes that can support the effective management of these alliances (Smyth et al. 2021).

Despite these challenges, the advantages of augmenting alliances far outweigh the potential difficulties. Alliances provide AOAD with access to a plethora of resources, expertise, and networks that can bolster its capacity to address the challenges of agricultural development and food security. They also provide a platform for knowledge exchange and learning, which can drive innovation and enhance the effectiveness of AOAD's programs and initiatives.

Moreover, alliances can enhance the legitimacy and credibility of AOAD's work. By working cooperatively with a diverse array of partners, AOAD can demonstrate its commitment to inclusivity and stakeholder engagement. This can enhance the organization's reputation and increase its influence at both the regional and global levels (Smyth et al. 2021).

The future of joint endeavors within AOAD will be characterized by the augmentation of alliances and the navigation of associated challenges. This will require the organization to adapt and change, but it also presents an exciting chance to increase its impact and help accomplish the Sustainable Development Goals. Through strategic and effective alliances, AOAD can continue to propel progress in agricultural development and food security in the Arab region.

7.3 Successful Collaborations: Impact on Agricultural Development and Food Security

Successful collaborations are the lifeblood of any organization striving to make a significant impact on a global scale. The AOAD is no exception. Its partnerships with various entities, ranging from non-governmental organizations (NGOs) to private sector companies, regional organizations, and international organizations, have been instrumental in driving agricultural development and enhancing food security in the Arab region.

One of the most notable collaborations is with the Food and Agriculture Organization of the United Nations (FAO). This partnership has been pivotal in implementing sustainable agricultural practices and promoting food security. Together, they have launched initiatives aimed at improving water management, promoting climate-smart agriculture, and enhancing the resilience of farming communities to environmental shocks.

For instance, the joint project in Darfur, Sudan, focused on water harvesting and improving water efficiency in agriculture. By introducing new irrigation techniques and training farmers on their use, the project has significantly increased crop yields while conserving water resources. This not only boosts agricultural productivity but also contributes to food security by ensuring a steady supply of food crops.

Another successful collaboration is with the World Food Program (WFP). This partnership has been key to improving water resource management in rural communities in South Sinai, Egypt. Through their joint efforts, they have empowered smallholder farmers by improving access to water, introducing innovative farming techniques, and establishing market linkages. These interventions have led to increased agricultural productivity and income, thereby enhancing food security at the household level.

AOAD's collaboration with the private sector has also yielded significant results. By leveraging the resources and expertise of private companies, AOAD has been able to drive technological innovation in agriculture. For example, the partnership with a leading agri-tech company led to the introduction of precision farming technologies in the region. These technologies enable farmers to optimize inputs such as water and fertilizer, leading to increased crop yields and reduced environmental impact (AOAD 2023a).

The impact of these collaborations on agricultural development and food security cannot be overstated. They have led to the introduction of innovative farming practices, increased agricultural productivity, and enhanced the resilience of farming communities to environmental and economic shocks. Moreover, they have facilitated knowledge transfer and capacity building, thereby empowering farmers to take charge of their own development.

However, the success of these collaborations is not without challenges. Issues such as lack of coordination, differing priorities, and resource constraints can hinder the effectiveness of partnerships. Therefore, it is crucial for AOAD to continuously evaluate and strengthen its collaborative efforts to ensure they yield the desired outcomes (Economic Forum 2016).

Furthermore, AOAD collaborates with international organizations and donor agencies to shape the global policy agenda. For instance, it actively participates in international forums like the World Food Summit and the Committee on World Food Security, advocating for the interests of the Arab region and contributing to global policy deliberations.

8 Looking Forward: Challenges and Future Directions for AOAD

8.1 Anticipating Future Challenges in Arab Agricultural Development

In the contemplation of Arab agricultural development's future, it is essential to anticipate the potential challenges that may obstruct its progress. These impediments encompass an array of elements, ranging from climatic transformations to technological deficits, necessitating comprehensive and proactive mitigation strategies.

Climate change threatens Arab agriculture. Climate change worsens water scarcity and land degradation, reducing agricultural productivity. Unpredictable weather and rising temperatures destroy crops and livestock, weakening farming communities and threatening food security (Li and Liu 2023).

The problem of policy formulation and execution must not be underestimated. To protect the region's unique ecosystems, policymakers must balance agricultural development's needs with environmental sustainability. Political variety and socio-economic disparities make this effort difficult.

Apart from climate, Arab agriculture's technical gap is a major issue. Despite global agricultural technology advances, this region's use is inconsistent. Regenerative agroecological agriculture requires significant investment and capacity building, which smallholder farmers, who dominate the region's agricultural business, cannot afford (Adom et al. 2022).

Moreover, agriculture's evolution is contingent on enhancing farming practices, a pursuit impeded by a lack of access to updated agricultural information and technical expertise. It is crucial to strengthen agricultural extension services and facilitate the dissemination of knowledge among farmers to bolster crop production and ensure sustainable farming practices.

The rapid pace of population growth in the Arab region is another pressing challenge. With an escalating demand for food, the pressure on agriculture to deliver will intensify. Accommodating this increased food requirement necessitates the expansion of agricultural productivity and efficiency, a task fraught with complexity due to the climatic and technological constraints (Rosenzweig and Tubiello 2007).

Policy making and implementation are difficult. Policymakers must balance agricultural expansion with environmental sustainability to protect the region's diverse ecosystems. The region's political variety and socio-economic disparities make this difficult (Adom et al. 2022).

The need for capital investment in agricultural infrastructure is a challenge that warrants attention. Upgrading irrigation systems, roads, and storage facilities, as well as investing in research and development to refine crop varieties and farming techniques, are prerequisites for substantial growth in the agricultural sector. Unfortunately, agriculture often struggles to attract the necessary financial resources due to the perception of high risk and low returns.

Arab agricultural development stakeholders can anticipate these future challenges and develop strategies and interventions to address them before they become insurmountable. This forward-thinking approach ensures food security and sustainable agricultural growth in the region.

8.2 Envisioning Potential Internal Obstacles in AOAD's Path to Success

In the performance of its mandated role, AOAD is not exempt from potential internal challenges that could influence its effectiveness in the future. These challenges are multifaceted and require insightful assessment for strategic mitigation.

One significant area of concern is the organization's financial health. AOAD's funding largely relies on the contributions of its member states and some external financing. Economic volatility in these countries or shifts in international funding priorities could potentially affect the regularity and size of these contributions. This financial instability may negatively influence the planning and implementation of long-term projects that are significant to achieving the organization's objectives. AOAD will need to explore diverse funding sources, possibly including private sector partnerships and green financing, to ensure its financial resilience (Peoplehum 2023; OpenMind 2023).

A related issue is the economic efficiency of the use of resources. With a broad mandate and a diverse membership, AOAD faces the challenge of prioritizing initiatives that yield the highest returns in terms of agricultural development and food security. Efficient resource allocation would require rigorous impact assessments and continuous monitoring and evaluation of projects to inform decision-making (Reshi 2021; OpenMind 2023).

AOAD's role involves significant coordination and collaboration, both within the organization and with external entities. Thus, the challenge of institutional coordination looms large. The risk of misalignments in engagements with potential and effective partner, public or private, may hinder the achievement of the organization's goals. Effective coordination mechanisms and strong leadership are critical to managing this complexity (Reshi 2021).

Human resources constitute another significant internal challenge. The demand for expertise in diverse areas such as climate-smart agriculture, agricultural economics, and technology transfer necessitates a highly skilled workforce. However, attracting and retaining such talent may prove difficult due to competition with other organizations and private sector entities as well as limitation of financial compensation as imposed by the regulatory framework in place. AOAD will need to ensure competitive compensation packages, opportunities for professional development, and a conducive work environment to overcome this challenge (Reshi 2021; Budhwar et al. 2022).

The last two decades have witnessed rapid technological advancements that have transformed the way organizations function. AOAD, too, faces the challenge of adapting to this fast digital revolution, although significant steps have been taken to align engagement with state-of-art digital technology. Harnessing technology can enhance the efficiency and effectiveness of the organization's operations, from project management to data analysis and communication. However, investing in technology and training staff to use it effectively will be crucial (Budhwar et al. 2022).

AOAD's legitimacy and credibility could be questioned if it fails to meet its member states' needs or involves them enough in decision-making. Keeping up the organization's reputation requires transparency, accountability, and participatory decision-making (Budhwar et al. 2022).

In addition, the challenge of change management is pertinent. As AOAD evolves to meet emerging needs and adopt best practices and cope with continuous changes, it will need to manage the change process effectively to ensure smooth transitions and maintain staff morale and performance (Errida and Lotf 2021).

8.3 AOAD's Prospective Strategies for Addressing Emerging Issues

Given the evolving challenges in Arab agricultural development, AOAD has outlined forward-looking strategies to address these emerging concerns. The crux of these strategies lies in leveraging technological advancements, fostering sustainable practices, enhancing human capital, and strengthening institutional frameworks.

A salient aspect of AOAD's strategies is the integration of advanced technologies into agricultural practices. By promoting regenerative and sustainable agriculture, which encompasses GPS, remote sensing, and internet of things (IoT) technologies, AOAD seeks to enhance crop yields and resource efficiency. These technologies enable farmers to apply resources such as water and fertilizers precisely where needed, reducing waste and environmental impact. Additionally, the introduction of farm management software can streamline farm operations, provide market information, and aid in decision-making (AOAD 2023a).

AOAD recommends climate-smart agriculture to combat climate change. These methods boost crop yields, climate resilience, and greenhouse gas emissions. This strategy requires conservation agriculture, agroforestry, and crop rotation. To mitigate the effects of climate change on agricultural yields, AOAD emphasizes the development and dissemination of drought- and heat-resistant crop varieties.

Recognizing that human capital is a vital asset, AOAD is committed to enhancing the skills and knowledge of those involved in the agricultural sector. Through comprehensive training programs and workshops, AOAD plans to equip farmers with the technical skills necessary to adapt to evolving agricultural trends and technologies. Additionally, AOAD aspires to foster a new generation of agricultural scientists and researchers by supporting academic and vocational programs in agriculture Development and food security.

AOAD also envisions strengthening institutional frameworks to provide robust support for agricultural development. This includes fostering a conducive policy environment that encourages investment and innovation in agriculture. AOAD intends to work closely with member countries to reform policy and regulatory frameworks, thereby facilitating easier access to finance, improving land tenure security, and promoting the commercialization of agriculture.

Furthermore, AOAD plans to intensify its efforts in agricultural research and development (R&D). The focus is to generate knowledge and innovate solutions tailored to the region's unique challenges. R&D initiatives would encompass various domains, including biotechnology, agronomy, and agricultural economics. The outputs of these initiatives would not only aid in solving current issues but also in anticipating and preparing for future challenges (AOAD 2023a).

The quest for resource optimization is another strategic pillar. Given the region's water scarcity, improving water use efficiency through advanced irrigation techniques and watershed management is paramount. Additionally, the AOAD endorses the reduction of post-harvest losses through improved storage and processing facilities, which could significantly enhance food availability (AOAD 2023a).

AOAD underscores the necessity of partnerships. By forging collaborations with international agencies, research institutions, and the private sector, AOAD can harness their expertise and resources. These partnerships would accelerate the transfer of technology, mobilize financial resources, and promote knowledge sharing (AOAD 2023a, d).

8.4 *Exploring Opportunities for AOAD's Future Growth and Impact*

Notwithstanding the imminent challenges, the future trajectory of the Arab Organization for Agricultural Development bears promising opportunities for growth and impact. Through seizing these opportunities, it can catalyze transformational change in the Arab agricultural sector and reinforce its commitment to regional food security.

A pivotal opportunity lies in the digitalization of agriculture. Embracing digital tools can overhaul traditional farming practices, enhancing productivity and sustainability. AOAD could play a pivotal role in advancing digital literacy among farmers and promoting the use of digital solutions such as digital soil and weather sensors, satellite imagery, and decision-support systems. Moreover, it can facilitate digital platforms for knowledge exchange, market information, and e-commerce, thus expanding market access for farmers (AOAD 2023a).

The upsurge in biotechnological innovations presents another considerable opportunity. By endorsing research and development in agricultural biotechnology, AOAD can facilitate the development and adoption of genetically improved crop and livestock varieties. These varieties, resilient to biotic and abiotic stressors, can substantially enhance agricultural productivity, contributing significantly to food security.

Sustainable intensification, an approach that aims to increase food production from existing farmland while minimizing pressure on the environment, also provides significant growth potential for AOAD. This concept integrates ecological and genetic techniques with socio-economic factors. The promotion of techniques such as agroecology, conservation agriculture, regenerative agriculture, and integrated pest management can result in considerable productivity gains while preserving environmental integrity (AOAD 2023a).

Enhancing agro-biodiversity is another avenue for growth. The Arab region is a center of origin for many vital crops, offering rich genetic resources. By preserving and utilizing this genetic diversity, AOAD can help improve crop resilience and adaptability to environmental changes, thereby boosting productivity and ensuring the sustainability of agricultural systems.

Regenerative agroecological agriculture advances sustainable agricultural growth. Farming with regenerative agroecology is ecological, socio-economic, and cultural farming. It enhances biodiversity, soil health, and ecosystem benefits. Regenerative agriculture could assist AOAD in building climate-resilient, sustainable farming systems.

The potential to strengthen collaborations forms an integral part of AOAD's growth opportunities. By fostering partnerships with international organizations, research institutions, and the private sector, AOAD can accelerate innovation, mobilize resources, and facilitate knowledge and technology transfer (AOAD 2023a, d).

Moreover, AOAD stands to benefit from capitalizing on the circular economy in agriculture. The circular economy approach aims to eliminate waste and continually use resources. This approach can be manifested in the form of agricultural practices like organic recycling, bioenergy production, and agro-industrial symbiosis. AOAD's encouragement of such practices can pave the way for a more sustainable and efficient agricultural sector.

Opportunities exist in the expansion of value chains and agribusiness development. By fostering an enabling environment for agribusiness, AOAD can stimulate economic growth, create employment opportunities, and enhance the competitiveness of Arab agricultural products in global markets (AOAD 2023a).

9 Conclusion and Future Prospects

9.1 Summarizing AOAD's Impacts on Arab Agricultural Development and Food Security

AOAD comprehensive strategy, which includes policy advocacy, capacity enhancement, technology dissemination, research, and collaborations, has had a profound impact on the growth and transformation of Arab agriculture over time.

One critical aspect of AOAD's contributions has been its role as an influential figure in formulating agricultural regulations in the Arab world. Through their provision of informed policy suggestions and technical guidance, they've enabled the creation and execution of agricultural strategies that bolster productivity, maintain sustainability, and open market accessibility. Such policymaking has catalyzed financial inflow into agriculture, revamped regulatory infrastructure, and sparked innovative growth (AOAD 2023k).

Another commendable achievement by AOAD has been its persistent efforts to fortify the Arab agricultural industry's capacity. A variety of training sessions and workshops conducted by the AOAD have equipped different stakeholders with the required expertise and insights to assimilate optimal farming techniques and up-and-coming technologies. Furthermore, they have encouraged younger individuals to participate in agricultural activities, fostering an upcoming generation of agricultural experts.

The AOAD's endeavors in the sphere of technology distribution have also been significant. They have championed the adoption of technologies such as modern irrigation, precision agriculture, water harvesting techniques, the nexus approach, and post-harvest management, subsequently increasing resource efficiency and productivity across the region. Additionally, these technological implementations have alleviated environmental repercussions, steering the sector towards sustainable agricultural growth (AOAD 2023k).

The organization's dedication to agricultural research and development (R&D) in its different sectors has also played a significant role in its positive outcomes. Their support for R&D initiatives has enabled the creation of fresh insights and pioneering solutions to tackle the region's agricultural difficulties. Such initiatives have led to the introduction of enhanced crop types, superior irrigation systems, and progressive pest management methods.

Moreover, AOAD's devotion to sustainable farming has sparked profound changes. By endorsing methods such as regenerative agriculture, conservation agriculture, agroforestry, and organic farming, AOAD has led a notable shift towards agricultural sustainability. These techniques have not only augmented agricultural output but also improved soil vitality, biodiversity, and climate adaptability (ICBA 2023).

The AOAD's role in bolstering food security in the Arab region is also noteworthy. Their initiatives focused on enhancing agricultural productivity, diminishing post-harvest wastage, and refining food storage and distribution mechanisms have made substantial headway in securing a consistent food supply (AOAD 2023l).

Additionally, AOAD's facilitation of partnerships with global organizations, research bodies, and private enterprises has been crucial. These partnerships have mobilized supplementary resources, hastened technology dissemination, and enabled knowledge exchange, thereby enriching the Arab agricultural sector and strengthening its resilience (AOAD 2023l).

9.2 Potential Scenarios for AOAD's Future Influence and Expansion

Future projections for AOAD indicate diverse scenarios hinged on various factors such as political will, economic trends, technological advancements, and environmental changes. Considering these factors, several potential scenarios can be envisaged for AOAD's future influence and expansion.

Under an optimistic projection, AOAD might witness a significant amplification in its influence and operations. This scenario presumes conducive circumstances like robust political commitment to agriculture, augmented funding, technological breakthroughs, and successful climate change adaptation. Here, the AOAD would likely boost its engagement in policy advocacy, capacity enhancement, technology transition, research, and collaborations. It could spearhead a broad digital overhaul of the agricultural sector, champion innovative biotechnologies, and cultivate holistic sustainability within the sector. Such an optimistic projection would yield major strides in agricultural productivity and sustainability, significantly bolstering regional food security (AOAD 2023a, d).

On the other hand, a pessimistic projection predicts less than ideal conditions. This situation could arise from factors like reduced funding, waning political support for agriculture, sluggish technological advances, and severe climate change repercussions. In this case, the AOAD's growth would be curtailed, and its influence could potentially wane. Its ability to foster agricultural advancement and food security would be compromised, and the progress made so far could be jeopardized.

A moderate projection offers a middle ground between optimistic and pessimistic scenarios. It presumes average levels of funding, political support, technological evolution, and climate change effects. In this scenario, the AOAD would maintain its existing operations and witness modest growth. It would still contribute significantly to agricultural advancement and food security, albeit at a reduced pace compared to the optimistic projection.

A revolutionary projection contemplates a significant shift in AOAD's strategic focus and operations. This scenario could be initiated by dramatic changes in the global or regional landscape, such as a global food shortage, a technological upheaval, or an intense acceleration of climate change. Under this projection, the AOAD would reorient its strategy and operations to accommodate the new context and tackle emerging challenges and opportunities. This might involve a stronger emphasis on areas like the water-energy-food nexus approach, the circular green economy, regenerative farming, smart agriculture, and conservation agriculture.

A stable projection foresees the AOAD maintaining its present course without substantial growth or reduction. In this case, the AOAD would continue to make consistent contributions to agricultural development and food security, retaining its influence and operations at their current level AOAD (2023a).

It's crucial to note that these projections are not definitive forecasts, but possible future pathways grounded in certain assumptions. They provide a glimpse into the range of potential futures for AOAD's influence and growth. The actual course will be influenced by various factors and decisions made by stakeholders. AOAD's capacity to adjust and innovate in response to these evolving circumstances will be a vital determinant of its future direction and impact.

9.3 The Continued Relevance and Importance of AOAD's Mission

AOAD's inception was based on a mission that continues to be just as critical today. Its mandate, aimed at enhancing agricultural growth and ensuring food security within the Arab region, remains a pivotal part of the struggle against persistent food insecurity and the overall economic progression of the region.

In a period marked by unparalleled climate change, rapid technological progress, and evolving global economic scenarios, the significance of the organization's mission is heightened. With climate change exacerbating issues like droughts, desertification, and water shortages, particularly in the Arab region, agricultural productivity faces immense threats. In this context, AOAD's mission to promote resilient and sustainable agricultural practices becomes crucial to safeguarding current production capacities and securing future food availability (AOAD 2023a; Devex 2023).

Technology has significantly reshaped the agricultural arena with breakthroughs such as precision farming, genetically modified crops, and advanced irrigation methods. However, the uptake of these technologies within the Arab region has been inconsistent due to factors like accessibility, affordability, and a lack of skilled personnel. Here, AOAD's function of encouraging technology transition, capacity enhancement, and research becomes critical to closing this technological divide and harnessing the power of contemporary technology for agricultural growth.

Economic aspects such as commodity pricing, trade regulations, and investment in agriculture considerably sway the development of the sector. AOAD's role in advocating for favorable agricultural policies, stimulating investment in agriculture, and encouraging regional cooperation assists in creating a supportive economic setting for agricultural advancement. AOAD's mission also has significant social implications. By fostering agricultural growth, AOAD aids rural development, poverty alleviation, women's involvement, youth empowerment, and job creation, addressing several of the region's primary socio-economic challenges. Furthermore, by advocating for food security, AOAD contributes to social stability, given that food insecurity can potentially incite social unrest.

The current global pandemic has brought the significance of food security sharply into focus. Disruptions in food supply chains have highlighted the need for robust national and regional food systems. In this context, AOAD's mission to improve food security strongly resonates, underscoring the need for unified efforts to bolster the resilience of the Arab region's food systems.

Looking ahead, the relevance and significance of AOAD's mission are expected to escalate. The Arab region is anticipated to experience quick population growth, which will considerably augment food demand. Climate change repercussions are predicted to exacerbate, posing bigger challenges to agriculture. Technological advancements will continue to present fresh opportunities and challenges. In this evolving scenario, AOAD's mission of promoting agricultural development and food security will continue to be highly pertinent and increasingly crucial (AOAD 2023a).

The ongoing relevance and importance of AOAD's mission are undeniable. In an increasingly unstable and uncertain world, the role of AOAD will be central to navigating the intricacies of agricultural development and food security in the Arab region. Thus, continuous support for AOAD and a stronger commitment to its mission are essential to ensuring a food-secure and prosperous future for the Arab region (AOAD 2023a, b).

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Chapter 3
An Insight into the Stability of Major Agro-Food Resources in Saudi Arabia

Abdalhaleem Hassaballa and Abdelrahim Salih

Abstract Agricultural practices in the Saudi Arabia (KSA) encounter numerous limitations, notably; among them are scarcity of water, insufficient skilled technical workers, saline water and soil, in addition to the particular increasing desalination expenses. Among all that, the Kingdom authorities along with the academics have discovered that the self-sufficiency plan set earlier was in fact leading to significant destruction of the KSA's rare groundwater resources. Thus, this chapter is oriented to assess the fluctuation in major-agricultural-scheme's cultivated areas over different parts of the Kingdom using remote sensing techniques. Six agricultural areas representing the most productive regions in the Kingdom were identified; namely, Riyadh, Al-Qassim, Haiel, Al-Jouf, Tabuk, and Eastern Province, then from which pilot study areas in each region were selected for studying and analysis any potential change in the agricultural area during the past 30 years (1990–2020). Based on the investigated pilot areas, the overall change in the cultivated lands, corresponding to their respective surface cover type as well as the agricultural activity practiced, has been confirmed as noticeable degradation in most of the Kingdom's regions, while a few regions denoted agricultural development. It was also inferred from the decadal change that the most recent decade (2010–2020) has witnessed the highest reduction in the vegetation cover, in which 53% of the agricultural lands all over the regions have turned into bare soils. This percentage reflects the effect of the government's legislation and regulation towards banning irrigation water over-use for better resources management.

Keywords Agricultural lands · Change detection · Fluctuation · Food security · KSA

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1 Introduction: Kingdom's Agriculture, General Statistics

1.1 Strategic Crops Overview

During the early 70's, the KSA originated an enormous strategic support for agriculture sector, as being a portion of an extensive model for import substitution advancement targeted at guaranteeing self-satisfaction, attaining secure food and refining the sustenance and richness of countryside publics (Al-Shayaa et al. 2012). The strategy yielded considerable expansion of crop's watered area, primarily wheat crop, expanded from below 0.4 million hectares (M ha) throughout 1971 to around 1.6 M ha in 1992 (Ouda et al. 2013; World Bank 2005). This was attained by launching contemporary agricultural technology; providing farm owners with supplies, together with interest-free financial loans; issuing land at no cost; and providing contemporary agricultural services (Al-Shayaa et al. 2012; Haider et al. 2021; Li et al. 2023).

Despite the fact that environmental circumstances are certainly not suitable, KSA has always given considerable significance towards the agricultural sector and also has considered it as the main concern within many improvement strategies. The sector was anticipated to obtain the desired economic growth aims with which secure food quantities, diversity in productivity, as well as reduction in the dependence on oil being as a principal source of the national revenue. Numerous government plans happen to be developed and applied in order to allow the accomplishment of such desired goals (Frenken 2009).

During the 1999's, surface irrigation was mostly used to irrigate permanent crops, whereas annual crops were primarily enjoying the new systems of pressurized irrigation (Table 1).

In 2005, the particular under-cultivation area was in fact 1.2 M ha, of which 1.0 M ha contained annual crops and 0.2 M ha of permanent ones. Throughout 2005, cropped area was 23% lower than its 1992 statement. Annual crops minimized by 33%, whilst the field those were occupied by enduring crops improved by 11.1%. In 2006, the actually farmed crops under irrigation system area covered about 1.2 M ha, in which 56% contained cereals products (mostly wheat, followed by sorghum then barley), 17% of fodder, 17% of other everlasting crops (mostly dates fruit) in addition to 9% of vegetables. In 2007, agriculture sector contributed about 3% of GDP, and the overall economically productive human power was 8.7 M or above 35% of the overall population (2005). The population of those economically effective in agricultural practices were approximated at 0.6 M in 2005 (Frenken 2009).

The increase in productivity of all primary crops has long been observed throughout KSA attaining self-reliance in numerous agricultural products. Many researchers (FAO 2009; Maqbool and Kerry 1997; Oxford Business Press 2010; Royal Embassy of Saudi Arabia, Ottawa, Canada (RESA) 2010) have documented this kind of progress. Based on Maqbool and Kerry (1997), the prosperous farming field in the kingdom managed to produce cereals such as wheat, sorghum, millets, and barley. Amongst the vegetables, potato, tomatoes, eggplant, watermelon, onions, and cucumber tend to be worth to note. Fruits such as date palm, grapes and citrus were

Table 1 Total cultivated area by crop type and method of irrigation*

	Traditional irrigation		Modern irrigation		Total	
	Area (M ha)	%	Area (M ha)	%	Area (M ha)	%
Permanent crops	0.14	74	0.047	26	0.18	15
• Dates	0.12	83	0.02	17	0.14	12
• Citrus	0.03	41	0.004	59	0.008	1
• Grapes	0.03	46	0.004	54	0.007	1
• Olives	0.04	39	0.006	61	0.01	1
Temporary crops	0.27	27	0.75	73	1.02	85
• Cereals	0.18	26	0.51	74	0.69	58
• Vegetables	0.03	38	0.06	62	0.09	7
• Fodder	0.06	24	0.02	76	0.24	20
Total (**)	0.41	34	0.79	66	1.2	100

(*) The information on the above table was compiled by the author from data-sources (Frenken 2009)
(**) The areas vegetables, cereals, and forage grown as permanent crops aren't involved. Generally, modern irrigation denotes drip irrigation of trees and sprinkler for forage as well as grains. Green houses cover an area for vegetation includes 3214 ha of cultivated as modern irrigation

also cultivated in big quantities and alfalfa continued to be the most popular fodder crop cultivated on massive patches. The most outstanding agricultural achievement in the kingdom was its accelerated change from importing wheat to its export (RESA 2010). Cereals were grown on 0.6 M ha, whilst the patches assigned for producing cereals along with hays quantities to around 0.7 M ha. Vegetables were cultivated over 1 M ha area. Nearly 0.42 M tons of tomatoes; 0.3 M metric tons (mt) of potatoes; 0.23 M mt of muskmelon and 0.28 M mt of watermelon were produced every year in the kingdom. Fruits were grown on around 0.19 M ha area, where their production surpassed 1.33 M mt. Likewise, dates used to be grown on an area of around 0.14 M ha whilst the production of dates was around 0.8 M mt. The KSA used to produce 0.46 M tons of chickens as well as 2.4 M eggs. The industry of livestock sector was also prospering at a fast rate as cows have enlarged to 0.33 M heads, camels to 0.82 M heads, as well as sheep to 16.1 M heads. The KSA used to produce a lot more than 1.2 M tons of milk as well as 0.16 M mt of steak (Samirad 2005).

1.2 The Relative Contribution of Strategic Agro-Products

The kingdom used to export dates, dairy foods, chicken eggs, seafood, chicken, fruits, vegetables, and flowers to marketplaces worldwide (RESA 2010). Self-sufficiency as well as the export of some goods, like dates and watermelons, was accomplished (Maqbool and Kerry 1997). Vegetables produced at a local scale satisfied 85% of internal use (Strategic Media 2009). KSA farm owners used to trade potatoes, carrots, tomatoes, and also pumpkins. In addition to that, 60,000 mt of vegetables tend to be transported to the nearby countries. Amongst fruits, strawberry is actually essential to highlight (Saudi Arabia Magazine 2001). Fresh-cut flowers were shipped to Netherlands (Strategic Media 2009). Saudi Arabia has reached self-sufficiency in several essential commodities through implementing new revolutionary technology (Al-Subaiee et al. 2005; FAO 2009).

Additionally, Saudi Arabia experienced remarkable success in the production of wheat crop for a long time and then after, become wheat exporter to many countries, such as China a (Al-Shayaa et al. 2012). A significant increase in the production of all fundamental foods and the KSA's self-sufficiency in a number of food products to feed its people happen to be documented by many researchers (Al-Shayaa et al. 2012; FAO 2009; Maqbool and Kerry 1997; Oxford Business Press 2010; RESA 2010). Alfalfa was initially cultivated as a forage crop, but it might be on small scale (Maqbool and Kerry 1997). The most notable agricultural achievement of the KSA was its fast change from wheat importer to the exporter (RESA 2010) continued to be under 10% and imports attained up to 40% for livestock items of the overall imports of agriculture (Fig. 1).

Nevertheless, recently, exports have already been entirely prohibited aiming to save water (Strategic Media 2009) and guarantee long-term sustainability and sustain its natural assets in very good situation for the coming generations. So, KSA chosed to roll back its plan on extensive agriculture to save its valuable water sources and concentrated in cultivating solely those crops with minimal water demands (Al-Shayaa et al. 2012). Steadily, significantly less area has been cultivated with wheat. Therefore, between the years 1994 and 2004, grains productivity accordingly decreased from 4.86 to 2.95 M mt while fruits production in addition to vegetables improved (Samirad 2005). The decrease was a result of a plan to dissuade farm

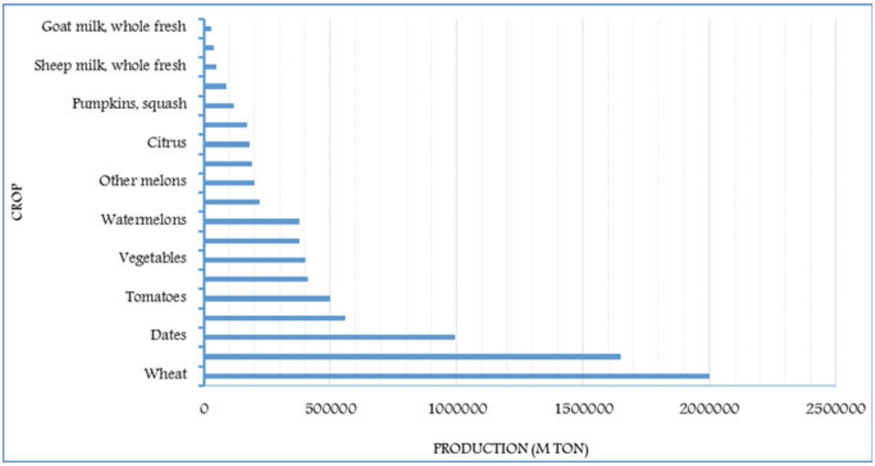

Fig. 1 Production of the agricultural commodities (MT), reported in 2008. The Figure was generated basing on data compiled by the author from (Al-Shayaa et al. 2012)

owners to cultivate a lesser amount of wheat and to promote diversity in crops in order to maintain the natural resources and reach sustainability.

1.3 Interpretation and Trend Analysis of the Cultivated Areas

As the Kingdom has reached superior self-sufficiency in wheat, potatoes, eggs, and fresh milk, these items have met 100% of its demands, whereas chicken production fulfilled 50% of domestic demands and overall fruits and vegetables supplied 65 and 85%, respectively (Strategic Media 2009). Nevertheless, this overproduction has placed the kingdom's resources (especially water) under stress and was definitely a consequence of over-exploitation of the resources. In fact, these growth and increase in agricultural production were seen as only short-lived and unsustainable. As a result, the Kingdom of Saudi Arabia has sought to focus on achieving permanent sustainability by implementing productive and protective agricultural strategies.

As stated earlier, the kingdom authorities along with the academic field have discovered that the self-sufficiency plan was in fact leading to significant destruction of KSA's rare groundwater resources (Alrwis et al. 2021; Al-Shayaa et al. 2012; Al-Subaiee et al. 2005). Accordingly, in 2008 the Kingdom's government took a decision to reverse this policy and introduced a new plan aimed at reducing the cultivation of crops that intensively consume water for instance wheat, and recommended growing valuable crops like fruits and vegetables (Alabdulkader et al. 2012; Al-Zahrani 2010; Al-Zahrani and Baig 2011; Ouda et al. 2013). The effects of this newly-set agro-plan on water assets sustainability and the self-sufficiency's achievement of food haven't been thoroughly examined. Therefore, this chapter aimed to analyze and monitor the spatial implications of this adopted plan by reviewing the recent historical agricultural fluctuations.

1.3.1 Selected Kingdoms'-Outskirts

This chapter deals with issues related to the productivity of strategic crops and their evaluation based on spatial and temporal perspectives. Thus, its main objective is to assess the potential fluctuations in cultivated areas in the main agricultural schemes over different parts of the Kingdom using remote sensing techniques. Accordingly, the specific objectives are as follows:

- To provide a statistical overview of agricultural projects in six different regions.
- To detect the extent of changes (±) in agricultural projects during the past 30 years.
- To analyze the production stability (in terms of cultivated area percentages) of the monitored schemes based on the obtained results.

This research covered six projects located within the most productive regions of the Kingdom, namely Riyadh, Qassim, Hail, Al-Jouf, Tabuk, and the Eastern Province. Figure 2 shows the regions of the Kingdom with reference to the selected study

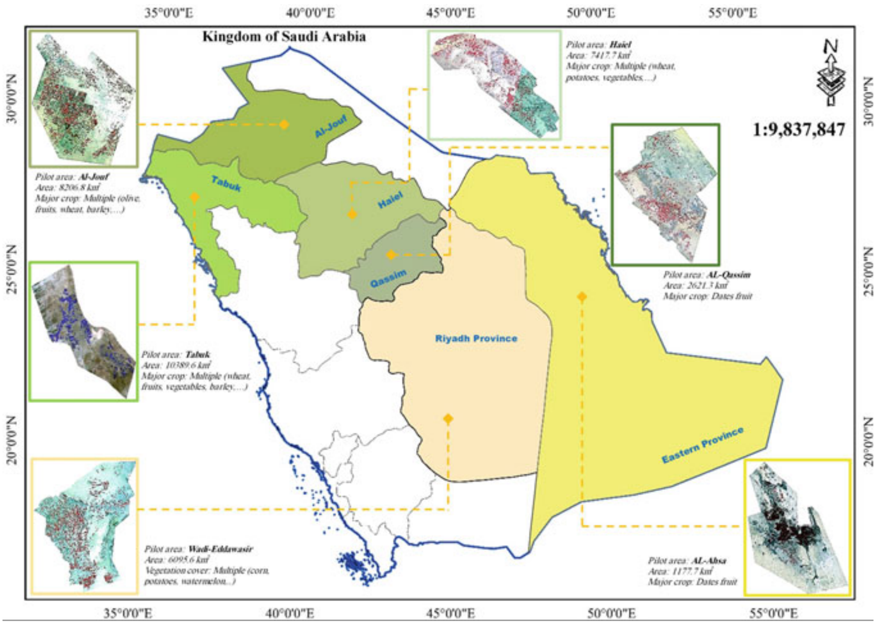

Fig. 2 KSA general layout and location of the study regions

regions. The experimental study regions were selected in each of the six regions for change analysis. The results of the study will provide information about the effects of the new agricultural policy on the selected agricultural areas during the past three decades and assess the most affected agricultural decade among them.

Riyadh Region

The Riyadh Region is geographically located in the middle of the country. It includes an area of 404,240 km^2 and has a population of 8,216,284, (Population Characteristics surveys 2017). It is basically the second-largest region in terms of both population and area, following Mecca Region and Eastern Province, respectively. The region features a hot desert environment with extended, very hot summer seasons, and brief quite moderate winters. The mean high temperatures are noticed in August, which is certainly around 43.6 °C. The region witnesses extremely little precipitation, particularly in summer times, however, it gets a reasonable quantity of precipitation in March and April. In addition, the Riyadh region is exposed to heavy dust storms accompanied by heavy dust, which limits visibility to less than ten meters (Climate and Weather 2022; Surface annual climatological report 2016). Among the most prominent agricultural areas in the Riyadh region are Al-Kharj, Harad, Wadi-Hanifa, and Wadi-Eddawasir, where multiple crops and fruits are grown.

The Eastern Region

The Eastern Province is the largest region in the Kingdom in terms of area, in addition to being the third most densely populated region after Riyadh and Makkah Al-Mukarramah. The region constitutes about 15.05% of the total population of the Kingdom and a third of its area is desert. As a result of the improvements made during the Green Revolution to irrigation and farming strategies, the areas of Hafr Al-Batin and Al-Ahsa Oasis became important sites for desert agriculture. Millions of palm trees characterize the Al-Ahsa region. In addition, the Ministry of Environment, Water, and Agriculture established an industrial unit to manufacture the production of Oasis dates, amounting to 5 tons per day. The oasis is considered one of the largest date-producing areas in the Kingdom of Saudi Arabia, and it also forms a large part of the overall economy of the province.

The Qassim Region

The Qassim Region is situated at the country's heart; it possesses a population of 1.3 M with an area of 0.06 M km^2. It is proven to be the "alimental basket" of the kingdom, because of its agricultural resources (Laessing 2010). Al-Qassim is definitely the wealthiest area per capita in the kingdom (Poverty in the Kingdom of Gold 2012). It is the seventh most inhabited area in KSA following Jazan and the fifth most densely inhabited. Al-Qassim region features a regular desert environment, recognized for its cool, wet winter seasons and for its hot, much less humid summer seasons. Al-Qassim region hosts over 8 M palm trees, turning it into one of the Middle East biggest suppliers of dates, producing a yearly quantity of 0.2 M mt of various luxurious dates that give the place a very high economic importance by exporting huge amounts of dates internally and externally.

Haiel Region

Haiel Region is the eighth biggest region by area, which is around 0.1 M km^2, as well as the ninth biggest region by population, with a population record of 0.7 M in 2019. The region accounts for ~ 2% of the kingdoms' population. The majority of the recognizable vegetation in Haiel is usually wheat, potatoes, and vegetables.

Al-Jouf Region

Al-Jouf is among the most fertile areas in the kingdom. In contrast to the majority of the country, areas of Al-Jouf feature a modest climate, and plentiful groundwater, enabling unusually substantial degrees of agricultural activity observed in the area. This area is known for growing olives as well as accounts for about 67% of the produced olives oil within the KSA (Retso 2013). Al-Jouf is the place of the widespread cultivation of palm trees and provides ~ 0.02 M mt of dates yearly (Wildberger 1997). Population evolution at the Al-Jouf area is mostly rapid, with an estimated total size of 0.52 M. Al-Jouf province lies inside a semi-tropical pressured belt that makes wind impose an impact in the area. Throughout winter season, an arid winds blow from the northeast, turning Al-Jouf climate into a steady and calm throughout the season.

Tabuk Region

Finally, Tabuk is a province of the kingdom that is situated across the northwest coastline of the kingdom, facing Egypt along the Red Sea. It owns an area of 0.14 M km^2 as well as a population of 0.9 M (Population Characteristics Surveys 2017). Tabuk is undoubtedly a productive commercial center, providing pilgrims moving through toward Mecca. Because of its modest environment, it's even the site of several dairy products and chicken farms. The area provides European countries with flowers, primarily statices, lilies, and gladiolas (Tabuk City Profile 2017).

The Pilot Study Areas

It is beyond doubt that the entire study area has undergone significant changes in terms of environment, social statement, ecology, as well as the demographic level over the past 30 years (Alrwis et al. 2021). The agricultural plots of interest within each region (including the most distinct surface cover surrounding the agricultural plots) were selected and allocated for analysis and potential change detection as shown in (Table 2).

The general concept was to reveal the extent to which agricultural schemes have changed (increasingly or decreasingly) during the past 30 years, over the 6 selected agricultural outskirts. However, only the most densely-cultivated locations within the regions were considered for pilot study area delineation, and then change detection analysis was achieved accordingly. Upon that, the overall region's change could be assessed in accordance with the measured change within each pilot study area for the studied period.

In fact, the percentages of change at each stage of the analysis were used instead of using surface cover area, as the overall regional area change could definitely be far greater than the pilot study does. Thus, proportionality analysis can lead to trend scenarios for all types of surface cover involved in the change process.

Satellite images (4 cloud-free for each of the 6-selected study areas) were acquired from Landsat satellite for the periods (1990–2020), having a 30-m resolution (Table 2). These images were obtained from the records of Earth Explorer data source of the United States Geological and Survey (USGS) (http://earthexplorer.usgs.gov/), and were calibrated by utilizing data explicit tools of ENVI (Ver. 5.3) software program, in which the digital number of the image's was initially turned into spectral radiance ($L\lambda$). Consequently, image's reflectance was produced through pixel's radiance calculation. Atmospheric rectification applications like dark object and haze elimination, as well as cloud masking were applied in order to rectify the sensor's radiance, making use of the specialized FLAASH correction model (Adler-Golden et al. 1999). Image enhancement has also been carried out so as to enhance the dissimilarity amongst images' features aiming to enhance the pictorial presentation of the apparent characteristics. This particularly included employing the array of inputs of numerical values to generate a different array of outputs.

Table 2 Properties of the extracted pilot study areas

Region	Pilot S. area	Geometrical info	Satellite images info				Surface features
			Sensor	Date	Path/ Row	Res	
Riyadh	Wadi-Eddawasir	***Area*** (Km^2): 6095.6 ***Location***: Lat. 20.60–21.00 °N Lon. 44.60–45.50 °E	Landsat-5(TM)	1990	165/ 046	30 m	Sand
			Landsat-7(ETM	2000			Soils
			Landsat-7(ETM)	2010			Urban area
			Landsat-8(OLI)	2020			agriculture
Eastern	Al-Ahsa	***Area*** (Km^2): 1177.7 ***Location***: Lat. 25.10–25.40 °N Lon. 49.20–49.50 °E	Landsat-5(TM)	1990	164/ 042		Urban
			Landsat-7(ETM)	2000			Vegetation
			Landsat-7(ETM)	2010			Sand
			Landsat-8(OLI)	2020			Soil
Al-Qassim	Al-Qassim	***Area*** (Km^2): 2621.3 ***Location***: Lat. 25.40–27.40 °N Lon. 42.60–44.39 °E	Landsat-5(TM)	1990	167/ 042		Sand
			Landsat-7(ETM)	2000			Soils
			Landsat-7(ETM)	2010			Urban area
			Landsat-8(OLI)	2020			agriculture
Haiel	Haiel	***Area*** (Km^2): 7417.7 ***Location***: Lat. 26.50–27.60 °N Lon. 41.20–43.20 °E	Landsat-5(TM)	1990	169/ 041		Sand
			Landsat-7(ETM)	2000			Rocks
			Landsat-7(ETM)	2010			Soil
			Landsat-8(OLI)	2020			Agriculture
Al-Jouf	Al-Jouf	***Area*** (Km^2): 8206.8 ***Location***: Lat. 29.20–30.56 °N Lon. 37.34–39.27 °E	Landsat-5(TM)	1990	171/ 039		Agriculture
			Landsat-7(ETM)	2000			Rocks
			Landsat-7(ETM)	2010			Soil
			Landsat-8(OLI)	2020			Sand

(continued)

Table 2 (continued)

Region	Pilot S. area	Geometrical info	Satellite images info				Surface features
			Sensor	Date	Path/ Row	Res	
Tabuk	Tabuk	***Area*** (Km^2): 10,389.6 ***Location***: Lat. 27.59–29.60 °N Lon. 35.38–37.18 °E	Landsat-5(TM)	1990	173/ 040		Agriculture
			Landsat-7(ETM)	2000			Urban
			Landsat-7(ETM)	2010			Rocks
			Landsat-8(OLI)	2020			Soil

1.3.2 Classification and Change Detection Mechanism

The obtained images were classified using supervised classification, where four primary classes were determined according to the dominancy of surface cover features at each region. However, the vegetation cover (sometimes described as agriculture) class was present all over the study areas beside the soil class. Several locations were identified visually in the images for training and validating data, aided by a sharp resolution's base map (0.6 m) supplied in ArcGIS (10.4) software program. ENVI 5.3 software program was thereafter employed to make a statistical representation of images class's reflectance. This stage is typically referred to as "signature analysis" and describes the reflectance range on every band, the variances, as well as the covariance of the total bands. The images were then pending to classification process through analyzing each pixel's reflectance and then selecting the signatures, which exactly resembled the utmost common object. The "maximum likelihood" classifier was employed herein, which is particularly a directed classification approach produced from a proposition that uses discriminant functionality to designate every pixel to the class with the uppermost probability (Ahmad and Shaun 2012). Such classification machine is regarded to provide more effective results when compared to other kind of models. Though, it is significantly slower due to the extra calculations considered in the process. Locations for data training and testing for the four classes were digitized as being areas of interest (AOI) to generate four recognized surface covers depending on the signatures recorded when reacting to the spectrum. Therefore, the precision in evaluating the classification was achieved by employing testing data, which usually are produced arbitrarily among the entire points, by rates of 40–60% representing testing as well as training points, respectively.

A matrix of error (referred to as confusion matrix as well) is normally employed as being a numerical way of depicting the precision of the categorized data. The matrix is actually a tabular arrangement of data that shows the relationship between the outcomes of the classification procedure corresponding to a reference spatial data. To be able to produce the error matrix, field observations as well as a Global Positioning System (GPS) or map details are essential. The kappa coefficient is also vital measure of classification precision. If the value of coefficient certainly equals to 0, it suggests no resemblance amongst the classification elements and the reference. When it equals to 1.0, then classification variables as well as the reference are entirely identical. Therefore, a greater kappa number implies a precise classification (Story and Congalton 1986). For more accuracy, omission and commission errors were also evaluated. In which, for each classification process, commission errors occur when the method assigns pixels to a particular class, which usually doesn't fit to it. The overall commission errors can be thereafter identified through an indicator called producer's accuracy. The producer's accuracy can be defined as the overall appropriately recognized pixels divided by the overall reference image's pixels. However, omission errors occur once pixels that actually are part of specific class, but classified as another. Errors of omission are identified by using the user accuracy indicator, which is a particular indicator that portrays the omission error's quantity wherever the total number of the appropriately identified class pixels are divided by the whole class pixels (Story and Congalton 1986).

With regards to the post-classification approach, the technique of image differencing has been followed and implemented at every two subsequent satellite images. This method utilizes statistics for detecting the changes in order to offer an in-depth presentation of the variations among the particular consecutive images. The resultant report incorporates a class-for-class type-differencing image. The investigation concentrates mainly on the original condition of the classification deviations. Therefore, for every primary condition class, the analysis determines the classes that the related pixels are transformed into, at the final-state image (Almutairi and Warner 2010). The change results are normally documented in terms of percentages, pixel counts, and areas (Assisting catalog of ENVI 5.3).

2 The Spatio-Temporal Variation in the Strategic Agricultural Goods

2.1 Assessing Recent and Past Cultivated Areas

Figure 3 presents sample-maps for the resultant classification for all nominated regions over the study areas at the initial (1990) and final (2020) time spans. A very-clear spatial variability in the class of vegetation cover was noticed, revealing that high retardation in the agricultural sector has taken place during the past 30 years [i.e. Al-qassim (Fig. 3d), Wadi-Eddawasir (Fig. 3e), and Tabuk (Fig. 3f)], where abandoned farmlands were occupied by either urban sprawl activity or covered by fallow lands (soil class). However, few expanding agricultural sectors could be noticed in Al-Jouf (Fig. 3b) region which could be due to the recent prosperity in agro-business. Hence, detecting the changes on a decadal basis was so vital in order to measure and assess the most dynamic period (1990–2000, 2000–2010, or 2010–2020) where the cereals cultivation ban has placed an influence.

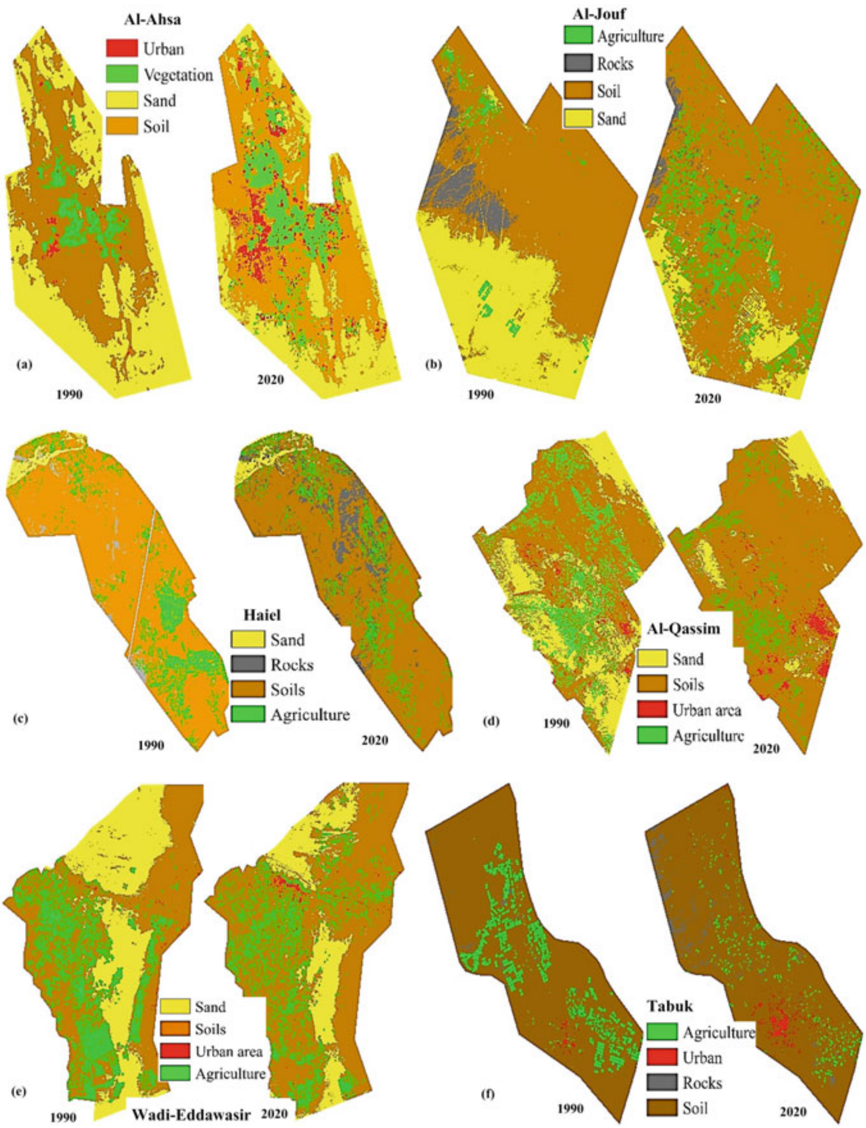

Fig. 3 Sample classification maps of the study area parts, **a** Al-Ahsa, **b** Al-Jouf, **c** Haiel, **d** Al-Qassim, **e** Wadi-Eddawasir, and **f** Tabuk, during the years 1990 and 2020

Table 3 displays the resultant confusion matrix acquired by the use of the previously outlined areas of interest (AOI) tools, so as to determine the precision metrics of the classification. The ENVI 5.3 software was employed for performing the task, in which the columns in the resultant table characterize the rates of right classes, while the rows indicate the percentage of the classifier's forecast.

Table 3 Confusion matrix for the classified images

		Class	Ground truth (%)				Commission	Omission	Producer accuracy (%)	User accuracy (%)
			Urban	Vegetation	Sand	Soil	(%)	(%)		
Al-Ahsa	Predicted	Urban	87.18	0.00	0.00	0.00	0.00	12.82	87.18	100.00
		Vegetation	0.00	100.00	0.00	0.00	0.00	0.00	100.00	100.00
		Sand	0.00	0.00	83.89	33.08	36.29	16.11	83.89	63.71
		Soil	12.82	0.00	16.11	66.92	18.31	33.08	66.92	81.69
		Total	100.00	100.00	100.00	100.00				
		Overall accuracy (%) = (498/623) 79.93%								
		Kappa coefficient = 0.71								
		Class	Ground truth (%)				Commission	Omission	Producer accuracy (%)	User accuracy (%)
			Agriculture	Rocks	Sand	Soils	(%)	(%)		
Al-Jouf	Predicted	Agriculture	100.00	0.00	0.00	0.00	0.00	0.00	100.00	100.00
		Rocks	0.00	83.06	0.00	17.60	78.89	16.94	83.06	21.11
		Sand	0.00	2.42	0.00	0.00	100.00	100.00	0.00	0.00
		Soils	0.00	14.52	100.00	82.40	22.48	17.60	82.40	77.52
		Total	100.00	100.00	100.00	100.00				
		Overall accuracy (%) = (2098/3009) 69.72%								

(continued)

Table 3 (continued)

		Class	Ground truth (%)				Commission	Omission	Producer accuracy (%)	User accuracy (%)
			Agriculture	Rocks	Sand	Soils	(%)	(%)		
		Kappa coefficient = 0.29								
		Class	Ground truth (%)				Commission	Omission	Producer accuracy (%)	User accuracy (%)
			Sand	Soils	Urban area	Agriculture	(%)	(%)		
Al-Qassim	Predicted	Sand	100.00	0.00	0.00	0.00	0.00	0.00	100.00	100.00
		Soils	0.00	99.82	0.00	0.00	0.00	0.18	99.82	100.00
		Urban area	0.00	0.18	100.00	0.00	2.40	0.00	100.00	97.60
		Agriculture	0.00	0.00	0.00	100.00	0.00	0.00	100.00	100.00
		Total	100.00	100.00	100.00	100.00				
		Overall accuracy (%) = (10,105/10116) 99.89%								
		Kappa coefficient = 0.99								
		Class	Ground truth (%)				Commission	Omission	Producer accuracy (%)	User accuracy (%)
			Sand	Rocks	Soils	Agriculture	(%)	(%)		
Haiel	Predicted	Sand	100.00	0.00	0.00	0.00	0.00	0.00	100.00	100.00
		Rocks	0.00	100.00	4.08	0.00	50.15	0.00	100.00	49.85
		Soils	0.00	0.00	95.92	0.00	0.00	4.08	95.92	100.00
		Agriculture	0.00	0.00	0.00	100.00	0.00	0.00	100.00	100.00
		Total	100.00	100.00	100.00	100.00				
		Overall accuracy (%) = (6090/6253) 97.39%								
		Kappa coefficient = 0.95								

(continued)

Table 3 (continued)

		Class	Ground truth (%)				Commission	Omission	Producer accuracy (%)	User accuracy (%)
			Agriculture	Rocks	Soil	Urban	(%)	(%)		
Tabuk	Predicted	Agriculture	81.74	0.00	0.00	0.00	0.00	18.26	81.74	100.00
		Rocks	0.00	67.29	0.00	0.00	0.00	87.14	12.86	100.00
		Soil	18.26	32.86	100.00	26.42	8.70	0.00	100.00	91.30
		Urban	0.00	0.00	0.00	73.58	0.00	26.42	73.58	100.00
		Total	100.00	100.00	100.00	100.00				
		Overall accuracy (%) = (1995/2269) 87.92%								
		Kappa coefficient = 0.69								
		Class	Ground truth (%)				Commission	Omission	Producer accuracy (%)	User accuracy (%)
			Sand	Soils	Urban area	Agriculture	(%)	(%)		
Wadi-Eddawasir	Predicted	Sand	100.00	1.49	0.00	0.00	6.81	0.00	100.00	93.19
		Soils	0.00	98.51	0.00	0.00	0.00	1.49	98.51	100.00
		Urban area	0.00	0.00	100.00	0.00	0.00	0.00	100.00	100.00
		Agriculture	0.00	0.00	0.00	100.00	0.00	0.00	100.00	100.00
		Total	100.00	100.00	100.00	100.00				
		Overall accuracy (%) = (20,973/21233) 98.78%								
		Kappa coefficient = 0.96								

The total classified surface cover accuracies for each region of the study area were found to be 79.9% (Kappa Coefficient = 0.72), 69.7% (Kappa Coefficient = 0.29), 99.8% (Kappa Coefficient = 0.99), 97.4% (Kappa Coefficient = 0.95), 87.9% (Kappa Coefficient = 0.68), and 98.7% (Kappa Coefficient = 0.96) for Al-Ahsa, Al-Jouf, Haiel, Al-Qassim, Wadi-Eddawasir, and Tabuk, respectively. This specifies the great correspondence between the classifiers as well as predictors.

As a way to measure the quantitative gain/loss over the pilot study areas, the 4 scenes at each portion of the study areas were used for discovering the changes encountering the agricultural lands (in particular) by using images differencing. The change was initially calculated by using a partial subtraction for every 2 under classification images for a specific period of time. Three subsequent decades were used for assessing the changes analysis: 1990–2000 (10 years), 2000–2010 (10 years), and 2010–2020 (10 years). However, Table 4 presents only one sample of the gain/loss values given in percentages (%) provided for the vegetation cover as an example aiming to depict the overall change (1990–2020) in this strategic surface cover. From the presented change results, it can be observed that nearly the majority of the areas occupied by agriculture in the 1990's have witnessed remarkable degradation so that quite noticeable portions of the cultivated areas have recently turned into some other kinds of land cover and/or land use. Referring to the resultant change values in Table 4, it is obvious that Tabuk area has witnessed considerable loss in the agricultural lands approximated to be 73.7% in 2020 compared to 1990, followed by Al-Qassim (59%), Haiel (21.5%), and Wadi-Eddawasir (18.8%). All the pre-stated reduction in the green areas was probably due to the policy-consequences placed against the cultivation of the water-exhausting crops, which have turned the class into fallow lands (soil class). In some areas such as Tabuk the urban sprawl has taken place upon the agriculture class that was previously existed during the early stages (1990's). On the other hand, some areas like Al-Ahsa and Al-Jouf achieved noticeable development in terms of agricultural area expansion reaching 160 and 400%, respectively.

2.2 Detection of Change in the Productive Zones (1990's–2020's)

Apart from the overall temporal change, an inter-decadal representation of the agricultural fluctuation throughout the stages of the studied period is presented in Fig. 4. This Figure revealed (in-depth) at which period of time the exports have already been entirely prohibited so as to save water resources, and accordingly less area has been cultivated with wheat. This obviously has taken place between the years 2000 and 2010 as can be observed from the drastic vegetation cover change shown over Al-Ahsa (Fig. 4a), Al-Qassim (Fig. 4c), Haiel (Fig. 4d), and Tabuk (Fig. 4e), where 37.4, 27, 2.2, and 13.7% of the agricultural land were abandoned or turned into

Table 4 Statistical representation of the detected changes (%) in pilot area's surface cover

		Urban	Vegetation	Sand	Soil	Row total	Class total
AL-Ahsa	Urban	80.65	1.69	1.54	9.12	100	100
	Vegetation	0	95.32	3.75	15.85	99.99	100
	Sand	0	1.12	55.47	3.36	99.93	100
	Soil	19.35	1.87	39.17	71.65	99.95	100
	Class total	100	100	100	100	0	0
	Class changes	19.35	4.68	44.53	28.35	0	0
	Image difference	951.65	161.27	− 41.01	11.44	0	0
		Agriculture	Rocks	Soil	Sand	Row total	Class total
AL-Jouf	Agriculture	6.54	18.03	6.95	10.43	100	100
	Rocks	3.59	18.04	1.73	0.49	99.99	100
	Soil	88.74	63.39	89.99	62.24	100	100
	Sand	1.12	0.50	1.33	26.82	100	100
	Class total	100	100	100	100	0	0
	Class changes	93.46	81.96	10.0	73.18	0	0
	Image difference	409.22	− 62.14	35.58	− 70.75	0	0

(continued)

Table 4 (continued)

		Sand	Soils	Urban	Agriculture	Row total	Class total
Al-Qassim	Sand	25.93	1.14	0.1	0.24	99.99	100
	Soils	69.37	93.01	50.50	80.86	99.99	100
	Urban area	1.09	2.46	47.82	0.53	99.98	100
	Agriculture	3.61	3.39	1.58	18.37	99.999	100
	Class total	100	100	100	100	0	0
	Class changes	74.07	6.99	52.18	81.63	0	0
	Image difference	− 71.44	43.58	129.64	− 59.13	0	0
		Sand	Rocks	Soils	Agriculture	Row total	Class total
Haiel	Sand	82.48	0.26	0.54	0.39	99.84	100
	Rocks	0.12	53.64	8.74	6.52	98.95	100
	Soils	14.81	40.18	83.59	69.84	99.57	100
	Agriculture	2.58	5.85	7.11	23.24	99.43	100
	Class total	100	100	100	100	0	0
	Class changes	17.52	46.36	16.40	76.76	0	0

(continued)

Table 4 (continued)

		Sand	Rocks	Soils	Agriculture	Row total	Class total
	Image difference	− 0.75	230.15	− 4.60	− 21.52	0	0
		Agriculture	Urban	Rocks	Soil	Row total	Class total
Tabuk	Agriculture	10.64	0.15	6.69	1.82	100	100
	Urban	1.01	44.61	0.81	1.21	100	100
	Rocks	7.86	0.31	23.94	3.19	99.98	100
	Soil	80.38	54.93	67.97	93.26	99.97	100
	Class total	100	100	100	100	0	0
	Class changes	89.36	55.39	76.06	6.74	0	0
	Image difference	− 73.67	387.57	175.72	4.48	0	0
		Sand	Soils	Urban area	Agriculture	Row total	Class total
Wadi-Eddawasir	Sand	50.99	1.11	0.16	1.79	99.99	100
	Soils	42.45	85.95	67.44	65.86	99.99	100
	Urban area	0.08	0.67	24.47	0.18	99.99	100
	Agriculture	6.46	12.27	7.92	32.16	99.99	100
	Class total	100	100	100	100	0	0
	Class changes	49.01	14.05	75.53	67.84	0	0
	Image difference	− 46.38	36.24	195.01	− 18.83	0	0

other surface cover feature, respectively. As a matter of fact, the agricultural retardation have significantly occurred even earlier than the 2000's over some regions, for instance Al-Qassim, Haiel, and Wadi-Eddawasir, have shown decrease in agricultural activities by 44, 38.9, and 33%, respectively. This reveals that water scarcity alarm has been effective since 1990's, which was confirmed by Samirad (2005) who reported that between 1994 and 2004 grains productivity decreased from 4.86 to 2.95 M mt whereas fruits production in addition to vegetables improved.

The ban on exporting wheat led to a decrease in the areas cultivated with wheat, which in turn, has resulted in a decrease in the percentage of self-sufficiency in wheat, as well as a decrease in irrigation water needs. On the other hand, despite the development in the areas of the fodder, vegetable, and fruit, crops persisted to be cultivated at a degree that met the growing needs of the local markets for these crops. Irrigated area was minimized from a maximum of 1.6 M ha in the year1992 into around 1.2 M ha in the year 2003. Also, the crops water requirement reduced

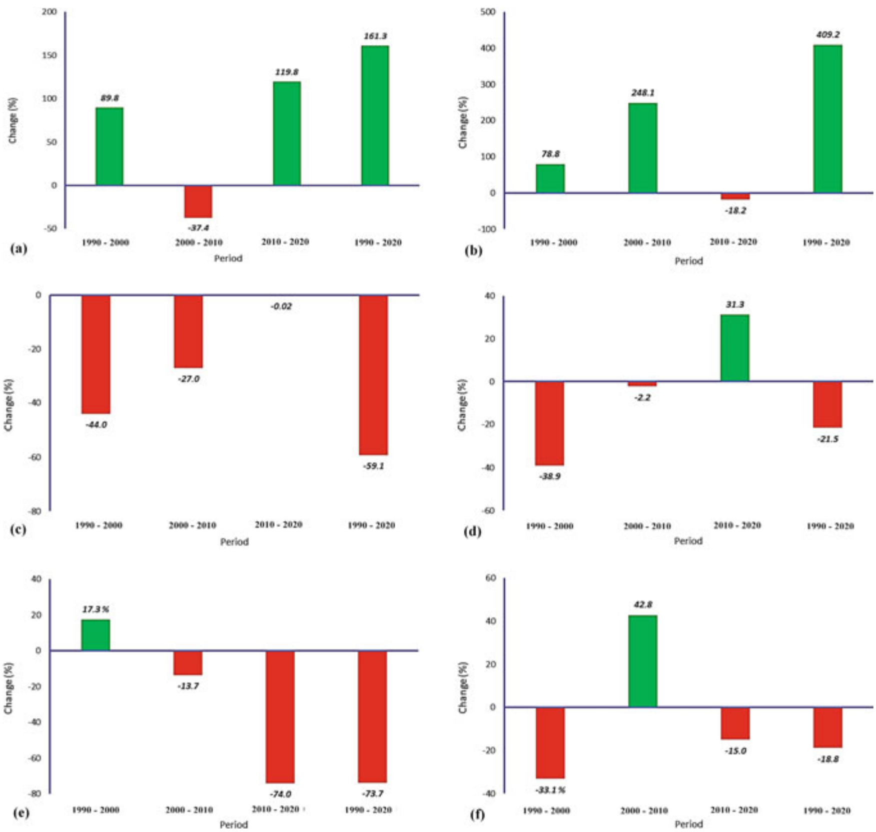

Fig. 4 Representation of the analyzed decadal fluctuation in the cultivated lands over **a** Al-Ahsa, **b** Al-Jouf, **c** Al-Qassim, **d** Haiel, **e** Tabuk, and **f** Wadi-Eddawasir

from a maximum of 22.3 km^3 in the year 1994 into ~ 17.3 km^3 in the year 2003, while agriculture's share of the GDP decreased from a maximum of 6.19% in the year 1994 down to 0.98% in in the year 2003 (Elhadj 2004; FAO 2009; Ministry of Agriculture 2011; Saudi Geological Survey 2012).

Agricultural activities in the Kingdom of Saudi Arabia faced many challenges, most notably the scarcity of water, the lack of skilled technical workers; water and soil salinity; desalination cost increase; agro-goods selling; lower prices of the agricultural products, higher cost of pest control and sanitary conditions (Al-Shayaa et al. 2012). Referring to all these challenges, the water problem is the biggest and most important challenge in KSA (Ray 2003), and this may be due to the lack of permanent estuaries and rivers or long-term bodies of water in Saudi Arabia, in addition to the depletion of groundwater resources (López et al. 2020; US Department of Energy 2002), resulting in a large gap between the rates of use and recharge, so groundwater is withdrawn from the aquifers faster compared to the rates of recharge. The problem is also exacerbated by the rapid population expansion, which may lead to exposing the agricultural sector to more water scarcity (Ray, 2003).

Al-Jabr (1984) indicated that the increase in urbanization happened because of the fast increase in migration from rural to cities, coupled with the growth of the urban population. In addition, economic development contributed to the availability of many non-agricultural professions that achieve better income than the agricultural field, which negatively affected traditional agricultural employment. In addition, the possibility of residents of cities and villages obtaining assistance from the authorities with regard to accommodation financing besides other kinds of related assistance. Research has indicated the interaction between aspects of weather, land use/cover (LULC), and their effect on ecosystem progression (Zeng et al. 1999; Barbier 2000) suggesting that LULC fluctuations were indeed the consequence of the strong environmental impact of commercial liberalization in addition to the globalization.

2.3 Analysis of the Agro-Products Stability

Based on the areas of the pilot study that were examined, the results of the total change (full period) in the cultivated lands in Saudi Arabia corresponding to the special LULC indicated deterioration in most regions of the Kingdom (i.e. Qassim, Hail, Tabuk, and Wadi-Eddawasir). The results of the evaluation indicate that the Qassim region is the most affected region based on the percentage (%) of agricultural degradation in the experimental region (Fig. 5a). On the other hand, the experimental areas in Al-Jouf and Al-Ahsa indicate remarkable agricultural development, which is attributed to many reasons, such as the progress of private sector activity, compensatory land solutions provided by the government and local authorities, and the inclusion and adoption of new trends and currents of agricultural sustainability technology. On the other hand, it can be inferred from the total-decadal agricultural change, the last decade (2010–2020) witnessed the highest change in the vegetation

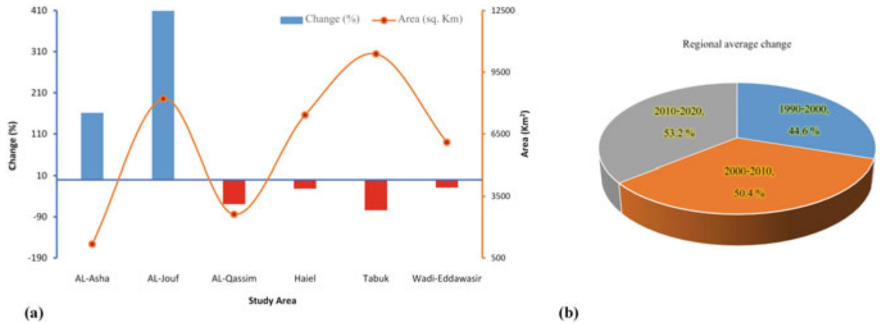

Fig. 5 The overall (1990–2020) change in the agricultural land based on **a** regional (spatial) and **b** decadal (temporal) differences

cover (Fig. 5b), as 53% of the agricultural land in Saudi Arabia was transformed into the barren soil.

Achieving food security is a situation that requires access to actual food resources to become sufficient, so that all people can use sufficient quantities of food products either through their own production, by obtaining them from the market, and/or through some other available option, and consumption of these food products must well-suited to meet the specific nutritional needs of individuals. The situation in which the authority took a decision in 2008 to stop exporting wheat prompted the enactment of a different plan in 2016 that includes providing assistance to grow wheat, increasing irrigation performance, and also arable land so as to gain high-value crops for instance, vegetables and fruits (Alabdulkader et al. 2012; Al-Zahrani 2010; Al-Zahrani and Baig 2011).

By 2010, the new plan influence was an evidence that the developed farm's areas have reduced to around 0.80 M ha; crops water requirements have dropped to around 15 km^3; the self-reliance in wheat also dropped to around 50%; the output of fruits and vegetables has demonstrated a little improvement in addition to the agricultural division's participation to GDP reached 2.38% (FAO 2009; Ministry of Agriculture 2011; Saudi Geological Survey 2012). Four progression scenarios at agricultural sector were actually equipped to measure the probable future influences of the novel agro-plans on water resources sustainability in KSA's as well as self-sufficiency in food for the coming 20 years.

The first scenario presumed that agriculture would keep up with the level of 2010 regarding self-sufficiency for the entire agricultural goods (68, 11.8, and 90.6 percentages for fruits, cereals, and vegetables, respectively). The second scenario presumed that the actual output of crops such as fodder and cereal would reduce until they are eliminated by 2030, while the farming of fruit and vegetables and fruits remains at the self-sufficiency status of 2010. The third scenario definitely made the identical suppositions as the second scenario concerning the productivity of fodders and cereals crops, however envisioned a steady self-sufficiency of 50% for fruit and vegetables through 2030. The fourth scenario presumed the progressive yet full cereal and fodder's output phasing out by 2020, in order to acquire maintainable irrigation amounts to cultivate fruits and vegetables. Such a way, through 2030, the same degrees of self-sufficiency might be achieved for the former two kinds of crops (Ouda 2014).

In fact, the way forward for agriculture and food encounters uncertainties that bring about significant inquiries and worries concerning its sustainability and performance. Uncertainties stick to various elements, such as population growth, nutritional alternatives, scientific improvement, revenue distribution, the condition of natural resources, global warming, the sustainability of peace (FAO 2017). No one realizes with accuracy how these elements will certainly change as time passes; nevertheless, they may be guaranteed to form the future.

Food requirement modifications may also be anticipated to be affected by developing demographic components and spatial places of populations. As an example, between 2015 and 2050 the number of individuals aged 15–24 predicted to be living in low- and middle-income countries (LMIC) is predicted to rise from around 1–1.2 billion. At the same time, some other regions will certainly have to adapt with fast-aging community members. Moreover, by 2050, two-thirds of the worldwide population might be residing in cities. The various food needs of old and young people, in addition to the various utilization forms, careers, and lifestyle conditions of urban and rural communities, will certainly impact the need for and quality of different food items as well as minimal nutritional power needs. Population dynamics can therefore be an essential determinant of future food need (FAO 2018).

Nearly one-third of the world's agricultural lands are moderate to highly deteriorated (FAO 2017). Such deterioration specifically affects dryland regions and negatively influences the quality of local populations' livelihoods, in addition to the long-term wellness of ecosystems. Worldwide, there is of options remaining for additional increasing agricultural areas. Furthermore, most of the available land is not appropriate for agriculture and considering agro-production would get substantial environmental, social and financial consequences (FAO 2014). Manufacturing, households, and agriculture are definitely the primary consumers of water, among which agriculture alone is accountable for 70% of all water withdrawals. In lots of low-rainfall locations over the Near East, Central Asia, and North Africa, as well as in India and China, farm owners utilize a lot of the available water assets, leading to a severe depletion of rivers as well as aquifers.

3 Conclusion

What could be produced, and whether developing and transforming agro-food requirements could be satisfied, is determined by the accessibility and also efficiency of resources, and notably of land and water. Most of these resources are actually under stress, and although technical progress has elevated production efficiency, research implies that production enhancement is degrading. Furthermore, reduction in agricultural output poses an unneeded stress on land, water as well as energy resources across the food value sequence. Dealing with this may enhance the environmental sustainability through the entire food system.

Recently, serious and ambitious plans for sustainable agriculture development have taken place among Kingdom's decision makers (Ghanem and Alamri 2023), which have been positively acknowledged by farm owners. For sure, introducing profitable and maintainable agriculture plans would need the assistance of extension programs and their individuals (Al-Shayaa et al. 2012). Having said that, ahead of beginning any program of agricultural extension, it is essential to assess the present perceptions as well as awareness of the agricultural extension providers concerning that exact endeavor. Taking into consideration such essential factor, Al-Subaiee et al. (2005) performed research to discover the perspective as well as insights of agricultural extension providers concerning agriculture sustainability. The research revealed that sustainable farming as well as its Inline actions were capable of handling lots of complications encountered by the Saudi agriculture for instance (i.e. weak fertility of soil; natural resources preservation like water and environmental protection).

Resource-conservation agricultural activities towards agro-land restoration, like conservation agriculture, climate-smart agriculture, organic agriculture, agroforestry and agro-ecology, might help balancing or perhaps increasing agricultural efficiency over time. However, investigation and investment are necessary to adjust this kind of solutions to local contexts and also make them perfect for farm owners.

To sum up, the spatial analysis of Kingdom's cultivated lands has confirmed a substantial reduction in the most of the regions' agricultural fields (i.e., Al-Qassim, Haiel, Tabuk, and Wadi-Eddawasir). It has been figured out that Al-Qassim region could be judged as the most influenced one based on the overall degradation percentage in the agricultural. On the other hand, Al-Jouf and Al-Ahsa have shown obvious development in the agricultural activities during the study period, which could be defensible by numerous reasons, for instant, the progression in private sector activity, the land's compensational solutions provided by the government and local authorities, or possibly the enclosure of the innovative directions and streams of technology for agricultural sustainability. Furthermore, considering the short run (10-years span), it can be inferred from the total agricultural change that the very recent decade (2010–2020) has witnessed the greater degradation in the vegetation cover, in which 53% of the agricultural lands all over the Kingdom's regions have turned into bare soils. This fact reflects the effect of the government's legislation and regulation towards banning water over-use for better resources management.

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Chapter 4
Water Security in Saudi Arabia

Khalid G. Biro Turk and Faisal I. Zeineldin

Abstract Water is critical for economic and social development in Saudi Arabia (KSA). It is essential to meet basic human needs, manage the environment, and sustain economic growth. However, despite the water scarcity and importance, the KSA faces severe challenges due to the unsustainable use of water resources. This chapter aims to comprehensively analyse water status in KSA concerning water resources, uses, security, policies, regulations, technologies, and prospects. The collected data used in this study were mainly from the published reports by the KSA Ministry of Environment, Water and Agriculture (MEWA). Also, the study analysis benefits from the most recent literature covering different water sector disciplines in KSA and similar regions. Based on the current status of water resources in KSA, the study suggested a conceptual framework which can be used to implement the water sector strategy established by the MEWA. The framework can set the problems, aims, procedures, services, action plans, and system monitoring for the water sector in KSA.

Keywords Policies and regulations · Saudi Arabia · Sustainability · Water sector · Water uses · Water security

1 Introduction

Water is vital for agriculture but also for industrial and tourism, social life, and nature conservation (Hussain et al. 2019). Water resource management in the twenty-first century faces complex problems as it is the most crucial resource for producing food

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and represents the essential central resource for humankind throughout human history (Ma and Gourbesville 2022). However, in arid and semi-arid regions, the management of water resources gets worse due to water scarcity, accessibility, irregular rainfall patterns, and high evaporation rates. Also, climate change can affect water availability in these regions through changes in the natural water resources process (Rajmohan et al. 2019).

The KSA covers a land area of ~ 2.25 million km^2 (Fig. 1), and the population increased from 25 million in 2007 to about 33 million in 2018, with an average annual growth rate of 3%. (Mumtaz et al. 2019; Alkhudhiri et al. 2019). The economy of the KSA depends mainly on oil, which covers ~ 90% of foreign export earnings and accelerates comprehensive development coupled with population growth and living standards (Chowdhury and Al-Zahrani 2015).

The major part of the KSA is arid, while the coastal strip along the Red Sea is a semi-arid climate. The rainfall in the southwestern part of the country is around 300 mm year^{-1} due to the southwest monsoon. However, the annual rainfall in the rest of the country is about 100 mm year^{-1} (Chandrasekharam et al. 2017). The dominant arid climatic conditions in the KSA make water resources management rather difficult. However, managing and developing water resources in the KSA are essential for sustaining population growth and growing the country's agricultural, industrial, and tourism sectors (Fallatah 2020). Groundwater is the KSA's primary water source for agriculture and human activities (Algaydi et al. 2019). Nevertheless,

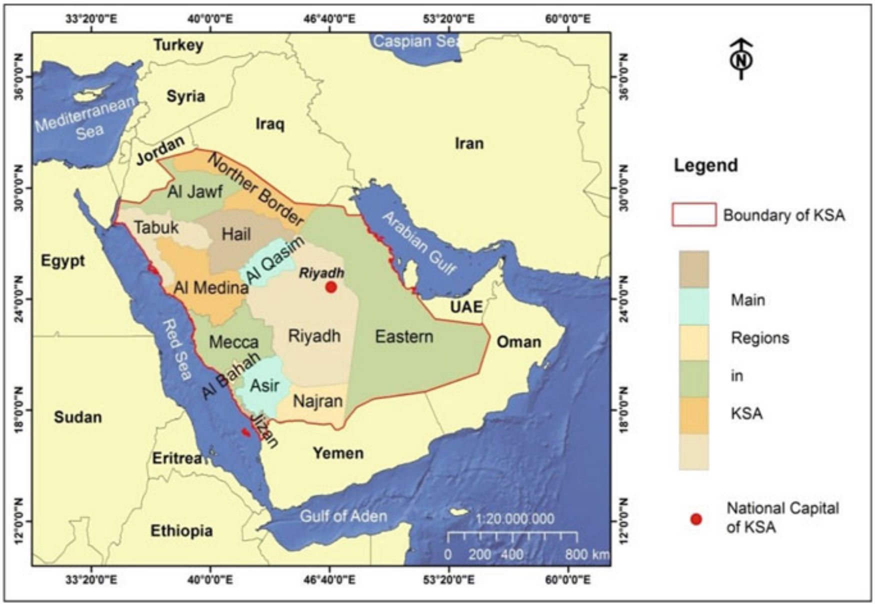

Fig. 1 Geopolitical location of Saudi Arabia. *Source* The map production was by the Water studies Center, KFU, in 2020

the over-exploitation of its current usage could be more sustainable and increases the potential threat to groundwater quality (Fallatah 2020).

In this chapter, we comprehensively analyse the water status in KSA, including water resources and uses, irrigation methods and techniques, water security, policies and legislation to water use in agriculture and current technologies for improving water utilisation. Also, an attempt was made to analyse the prospects of the water situation concerning use and scarcity.

2 Water Resources

The KSA water resources are categorised into conventional (surface water, renewable and non-renewable groundwater) and non-conventional (desalinated seawater and reclaimed urban water).

2.1 Conventional Water Resources

Water is vital to basic human needs, environmental management, and economic growth. However, conventional water resources in the KSA are limited and challenged by deficient precipitation, i.e. the annual average rainfall is 59 mm; harsh climactic conditions, i.e. in summer, the temperature can reach 55 °C; population growth; and extensive uses of the agricultural sector (Ghanim 2019). These challenges have affected the sustainability of water resources and degraded renewable and non-renewable freshwater resources. In addition, it can negatively impact the country's environment and economy. Therefore, the vision of 2030 has provided opportunities to enhance water use efficiency in the agricultural sector and reduce the annual extraction from non-renewable water resources. For instance, due to the implementation of the National Water Strategy, the annual extraction of non-renewable groundwater dropped to 15.5 BCM in 2019 and to 13.8 BCM in 2020 (MEWA 2020).

2.1.1 Surface Water

The KSA is devoid of natural permanent rivers or lakes. The surface water represents the torrents and floods resulting from rainfall and what go from it in reefs and valleys. Surface water runoff into valleys and down streams occurs whenever a powerful storm occurs in upper stream drainage basins. Most of the torrents and rainwater are in KSA's western and southwestern regions. A study of rainfall data over 64 years indicated that the average annual rainfall in KSA ranged from 4 to 300 mm (Amin et al. 2016). The western and southwestern regions had the highest mean annual rainfall, 300 mm year^{-1}, while the north-western and south-eastern parts had the

Fig. 2 King Fahad Dam in Wadi Bisha of Jizan region built in1997. *Source* Water studies Center, KFU in 2003

lowest, 4–50 mm year^{-1}. The occurrence of rainfall in KSA is scarce and highly varied from year to year. In Al-Qasim, in the country's central region, the rain was 37.2 mm in 2017, while it was 292 mm in 2018 (MEWA 2017; MEWA 2018). The flash in the southwestern mountainous regions is infrequent (Abu-Rizaiza and Allam 1989).

The total number of constructed dams in 2020 in the KSA reached 532 (MEWA 2020), of which 51% have been located in the western and southwestern regions of (Mecca, Asir, Jizan, Al Bahah and Najran) with a total storage capacity of about 2.0 billion cubic meters (BCM). The primary purposes of the dams are to harness surface water, control floodwater, provide drinking water for cities and divert water for agriculture (Baig et al. 2020). For example, the King Fahad dam (Bisha dam), as shown in Fig. 2, is a big dam in the Kingdom with a storage capacity of 325 MCM (FAO 2009). Its primary purposes are flood control, municipal water supply, irrigation, and groundwater supply recharge.

2.1.2 Renewable Groundwater

The Renewable Groundwater represents floods and surface runoff that naturally replenish sediments of valleys and discoveries and eventually recharge shallow alluvial aquifers in KSA. The alluvial aquifers are unconfined aquifers of a thickness that infrequently surpasses 100 m, with an average width of about 1 to 2 km and a length that could run up to 10 kms (Omar and Mohamed 1989; Fallatah 2020). Their mean annual recharge is 900 Mm^3. About 80% of it occurs in alluvial aquifers of the western and southwestern regions, representing 10% of the country area. The mean annual surface runoff was estimated to be about 2000 Mm^3, 30% redirected for agriculture, 45% infiltrated for recharging the groundwater aquifers, and 25% lost by evaporation (Omar and Mohamed 1989; Fallatah 2020). The alluvial renewable groundwater resources usually are used for municipal and agricultural purposes.

2.1.3 Non-Renewable Groundwater

The non-renewable groundwater characterizes a humongous amount of fossil water formed thousands of years ago in deep confined aquifers at depths of 150–1500 m (FAO 2009). Numerous studies indicated that the fossil groundwater in KSA is stored in seven major consolidated sedimentary old-age aquifers: Saq, Wajid, Minjur, Dhruma, Wasia, Umm Er-Radhuma, and Dammam (Abdulrazzak 1995; FAO, 2009; Chowdhury and Al-Zahrani 2015). Most deep confined aquifers are located in KSA's eastern and central regions. The water reserves estimate of the non-renewable groundwater aquifers of the KSA were shown to be 259–761 BCM, with a limited effective annual recharge rate of 2.4 BCM (Chowdhury and Al-Zahrani 2015; Fallatah 2020). However, the FAO (2009) indicated that the reserve estimate in the KSA is 253 BCM as a proven resource, 405 BCM as a probable resource, and 705 BCM as a possible resource. This is because the agricultural and industrial activities in KSA mainly depend on the fossil water of the deep aquifers. Table 1 shows details of the deep confined aquifers in the country.

2.2 Non-Conventional Water Resources

2.2.1 Desalinated Seawater

The KSA leads the world in producing desalinated seawater for public use. Its production capacity is 51% compared with Arabian Peninsula countries and 19% with global countries (Abdulrazzak 1995). However, the KSA's natural water resources are limited and cannot meet the urban water demand (Ouda et al. 2018). By 2020, the Saline Water Conversion Corporation (SWCC, 2023) reported 32 desalination production systems on the eastern and western coasts. In 2020, the total freshwater production reached 1.9 BCM, of the daily production of 5.9 MCM of desalinated water. The eastern coast plants were set to supply desalinated water to Riyadh and Al-Qasim cities. In contrast, the western coast plants were to supply holy Mecca, Jeddah, Al-Medina, Tabuk, Abha, Asir and Jizan regions (SWCC 2014). The SWCC annual report of 2016 showed that 58.4% of the desalination seawater diverted to the KSA cities comes from the east coast while 41.6% from the west coast. As

Table 1 Deep fossil aquifers in the KSA

Aquifer	Location	Proven reserve (BCM)	Probable reserve (BCM)	Possible reserve (BCM)	Depth (m)	Water quality (ppm)	Yield (l/s)
Saq	Tabuk	65	100	200	2000	< 1000	Tabouk (9–28), Hail (13–19), Al-Qasim (10–110)
Wajid	Najran	30	50	100		< 1000	Wadi Aldawasir (10–100)
Minjur Dhruma	Riyadh	17.5	35	85	1200–1500	1200–15,000	
Wasia	Riyadh	120	180	290		15,000	
Umm Er-Radhuma	Hraad	16	40	75	240–700		4–32
Dammam	Salwa	5	5	5	80	< 1000	

BCM = billion cubic meter; ppm = part per million or mg per liters; l/s = liter per second
Source Water Atlas (1995) and Chowdhury and Al-Zahrani (2015)

shown in Fig. 3, the annual productivity of desalination seawater increases annually with a variable rate of 5.8–13.3% to meet the demand increase for freshwater in the country's growing cities. The production of desalination seawater developed from 997 MCM in 2012 to 1.4 BCM in 2016 (SWCC 2016). All the freshwater produced by the SWCC is directed to municipal uses, representing 63% of total demand and 37% from renewable and non-renewable groundwater (MEWA 2018).

2.2.2 Reclaimed Urban Water

Treated sewage water (TSW) is an essential alternative water resource for reuse in the agriculture sector in KSA. Also, it can alleviate the pressures of pumping groundwater for irrigation purposes.

Due to the limitation of water resources, many countries across the Globe resumed reusing TSW for agriculture; landscaping and industrial cooling purposes (FAO 2009). Although the Kingdom has a high capacity of TSW, a fraction of it is being diverted for reuse in the agriculture or industry sectors. The rest of the sewage water is dumped into the Red Sea or Arabian Gulf (Chowdhury and Al-Zahrani 2015). Ministry of Economic and Planning (MOEP) reported that the production of TSW in KSA increased with an annual rate of 9.3% from 2004 to 2008, while the reclaimed quantity in 2008 was 730 MCM (MOEP 2010). However, the statistical book of the Ministry of Environment, Water and Agriculture (MEWA 2018) reported that the Kingdom established 91 sewage-treated plants across the country with a yearly

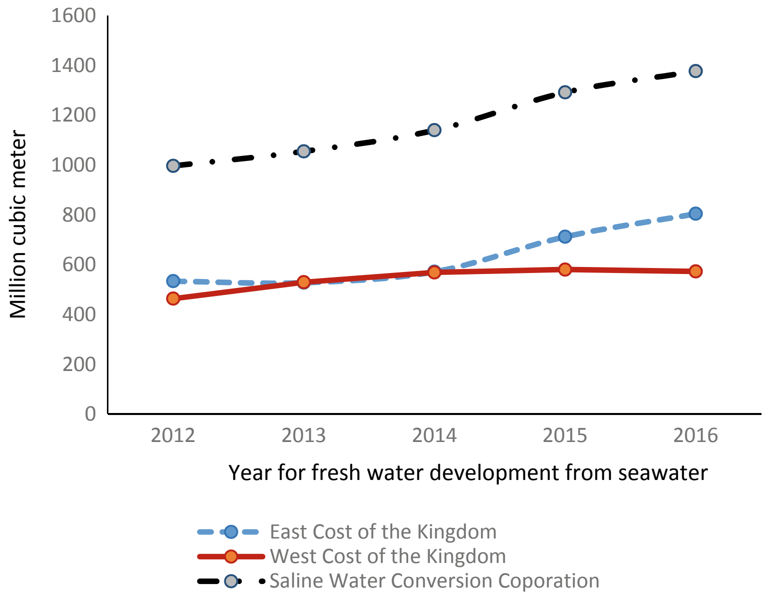

Fig. 3 Development of desalination seawater production in KSA (2012–2016). *Source* SWCC (2016)

production of 1.7 BCM. The highest producer regions in the KSA for TSW, respectively, were Riyadh (480.1 MCM), holy Mecca (431.3 MCM), Eastern (404.3 MCM) and Al Medina (128 MCM).

3 Water Uses

The total water demand in the KSA rapidly increased from 17,447 MCM in 2010 to more than 25,990 MCM in 2018 (Fig. 4). However, information on water use between 2010 and 2018 shows high demand in the agricultural sector compared to municipal and industrial sectors (Table 2).

Based on data shown in Table 2, the annual agricultural water demand was 6 times higher than the municipal one during 2010–2018 since there was an embargo on water consumption by the agricultural sector (Chandrasekharam et al. 2017).

Irrigated agriculture utilises almost 82–83% of the demanded water in KSA between 2010 and 2018. The water consumption for the different agricultural products in 2016 (Fig. 5) indicated that alfalfa and dates are the dominant water users in the KSA (Baig et al. 2020).

The municipal water quantities show spatial disparities in KSA, ranging from a minimum of 31 MCM in Najran to a maximum of 1027 MCM in Riyadh (Fig. 6). About 85% of municipal water was consumed domestically, while the remaining

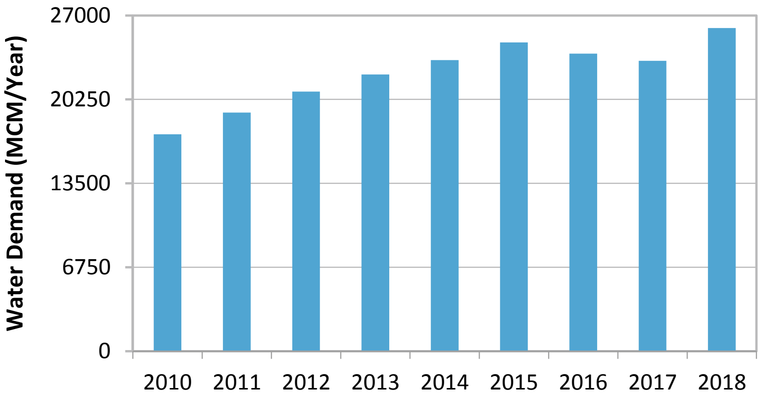

Fig. 4 Total water demand in KSA during 2010–2018. *Source* MEWA (2018)

Table 2 Annual water demand for the main sector in KSA (MCM)

Sector	Years								
	2010	2011	2012	2013	2014	2015	2016	2017	2018
Municipal	2284	2423	2527	2731	2874	3025	3130	3150	3392
Industrial	753	800	843	890	930	977	1015	1000	1400
Agricultural	14,410	15,970	17,514	18,639	19,612	20,831	19,789	19,200	21,200
Total	17,447	19,193	20,884	22,260	23,416	24,833	23,934	23,350	25,992

Source MEWA (2018)

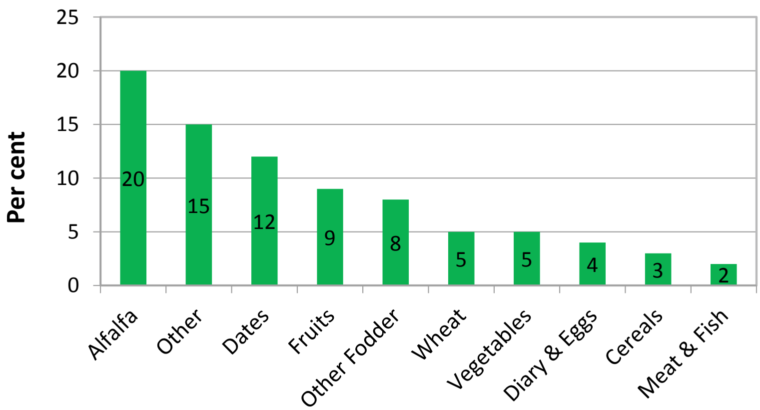

Fig. 5 Agricultural water use in 2016. (Adapted from Baig et al. 2020). Dates were excluded from fruits and wheat from cereals. Other uses indicate pesticide and fertilizers applications and the leaching requirements

15% was commercially used. Baig et al. (2020) estimated the average per capita water use at 97 m^3 $year^{-1}$ in 2017 in KSA.

Industrial water uses have increased from 753 to 1400 MCM between 2010 and 2018, an increase of 7.5% (Table 2). Also, KSA consumes over 1600 million m^3 $year^{-1}$ of water for producing crude oil (Sakhel et al. 2013). Moreover, industrial water use is projected to increase by 50% in the coming 15 years (Baig et al. 2020) due to the rapid growth of intensive industrial water uses like petrochemicals, fertilisers, mining, cement, steel, and food production (Ouda 2014b).

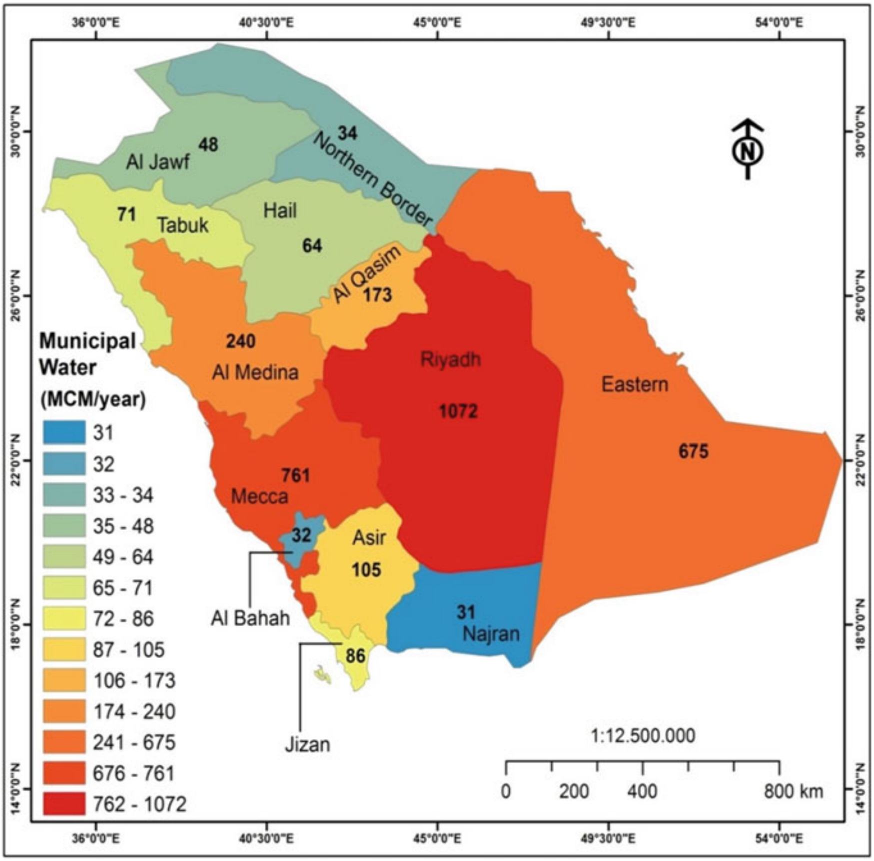

Fig. 6 Municipal water demand for the different regions in KSA during 2018. *Source* MEWA (2018). The map production was by the Water Studies Center, KFU, in 2020

4 Irrigation Methods and Techniques

4.1 Conventional Irrigation Methods

In the early 1900s, most irrigation methods were surface irrigation, done by flooding the land with water. The driving force of the water flow is gravity; henceforth, gravity flooding was used as an alternative term (Hart et al. 1980). Water was initially allowed to spill over rivers or artesian springs to flood the adjacent land; the method was called uncontrolled flooding. In the eastern region of the KSA, before the 1950s, uncontrolled flooding was practised nearby the hot springs (Euons) of Al-Ahsa oasis (Fig. 7). Later, the uncontrolled flooding methods evolved into controlled flooding methods such as basin, border and furrow surface irrigation. In the Kingdom, flooding methods have been used to irrigate date palm trees, citrus trees, vegetables and cereals crops. However, due to inadequate management of irrigation water using flooding methods has resulted in excessive water losses and tail-water runoff (Turbak and Morel-Seytoux 1988). Since sandy soils of high infiltration rates dominate most of the irrigated agricultural regions of the KSA, flooding methods with current severe water scarcity status are not recommended.

4.1.1 Uncontrolled Flood Irrigation Method

It was a kind of surface irrigation in which croplands were irrigated regardless of the low water use efficiency or uniformity (Walker 1989). It irrigated low crop value or land for grazing or recreation. A field irrigated by uncontrolled flood irrigation method (UFI) is mostly flooded with water that soaked into the soil to supply soil water for the roots of plants or trees. The UFI has prevailed in regions where water supplies were ample. For example, in the KSA, the UFI method was used in the eastern region et Al-Ahsa Oasis, where spring waters were plenty and easy to divert onto the nearby farms and orchards.

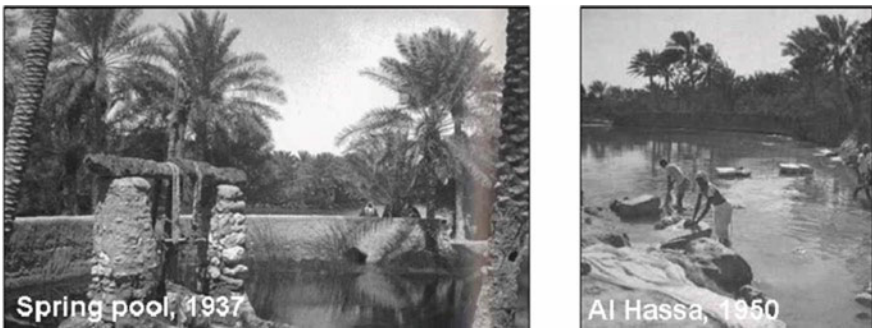

Fig. 7 Historical hot springs in Al-Ahsa Oasis. *Source* Al-Tokhais and Rausch (2008)

Table 3 Suggested basin areas for different soil types and rates of water flow

Soil type			
Sand	Sandy loam	Clay loam	Clay
Unit areas (ha/100 l/s)			
0.067	0.2	0.4	0.67

Source Adapted from Booher (1974)

4.1.2 Basin Irrigation Method

Basin irrigation is the simplest surface irrigation method constructed by hand. Basin sizes for various soil textures and inflow rates were empirically suggested by a method by Booher (1974), as shown in Table 3. Basin shapes are square but can also exist in irregular and rectangular configurations. An opening in the perimeter dike of a basin was set to supply water from an adjacent ditch. Inside the basin, the inflow of water is undirected and uncontrolled. The basin irrigation method has been used in most of the agricultural regions of the Kingdom, particularly in areas with small field layouts. However, due to the prevailing sandy soils in most of the Kingdom's agricultural regions, the authorities do not recommend the adoption of basin irrigation.

4.1.3 Border Irrigation Method

It is a surface irrigation method subdividing a field into graded strips by installing parallel dikes or border ridges. It suits soils with moderately low to reasonably high intake rates (USDA-SCS 1974). Border or strip irrigation is a modification of the conventional flood irrigation method. It conserves water by using the strip borders along each side of a tree line, thus limiting irrigation to half or less of the date palms floor area. Due to the slope's effects, the stream size per unit width must be significant following a tillage operation but smaller than basins. The accuracy of the field topography is also critical; nonetheless, the extended lengths enable better levelling using farm machinery. In the KSA, regarding border irrigation, water is applied to diked rectangular strips of length varied from 10.0 to 20.0 m, a width from 3.0 to 4.0 m, and spacing between centerlines of the strips of ~ 7.0 m. Irrigation occurs by allowing the flow to advance and infiltrate along the strip from a head ditch. However, larger inflow rates are engaged when the field slope is tiny.

In the Kingdom, the strip irrigation method is commonly used for young date palms. Besides, other crops like alfalfa, vegetables and citrus trees are intercropped between the young date trees. Therefore, to achieve high efficiencies, farmers must monitor the progress of water flow over the field, and sound judgment is required to terminate the inflow at the appropriate time. However, poor design and judgment may lead to reduced efficiency.

4.1.4 Furrow Irrigation Method

Furrow irrigation is a surface irrigation method that requires accurate field grading. It has small shallow channels installed evenly spaced down the slope of the field. Furrows vary in shape and size; they have parabolical cross-sections, flat bottoms, or about a 2–1 side slope (USDA 1979). Furrow grades should be 1.0% or less, but in an arid region like the KSA, furrow grades can be as much as 3.0%, where soil erosion from rainfall is not a hazard. Water flowed in at the high end and conveyed in the small channels to the locality of plants growing in or on beds between the channels. Water flowed in at the high end and conveyed in the small channels to the places of plants growing in or on beds between the channels. The application of enough irrigation water is aiming to achieve lateral penetration. Most vegetable and cereal crops in the KSA can be irrigated with furrow irrigation except fruit trees or crops are grown in ponded water, such as rice. The Furrow irrigation method is suited most to the medium and moderately fine-textured soil of relatively high available water holding capacity and conductivities, allowing water movement in horizontal and vertical directions. The movement of applied water by the furrow irrigation method on coarse-textured sandy soils is downward and has slight lateral penetration.

4.2 Improved Surface Irrigation Methods

4.2.1 Raised Bed Planting (Altadwees)

Raised beds of 0.20–0.40 m height are formed around the trunk of mature palm trees with a width of 2.00–3.0 m, and water flows in the wide depressed areas on the beds' sides, as shown in Fig. 8a (Al-Taher 2015). Losses due to evaporation are thus reduced when irrigation water flows alternately on each side of the raised beds. Furthermore, the method is suitable for irrigating mature palm trees with no intercropping as the canopies of the palms prevent such practice. Therefore, the technique is among the improved surface irrigation methods that Saudi Irrigation Organization (SIO) encouraged for water savings.

Fig. 8 Improved surface irrigation methods. **a** Raised bed planting; **b** Circular depression; **c** Strip irrigation. *Source* Water Studies Center, KFU, 2010

4.2.2 Circle Irrigation (Circular Depression)

Circle irrigation creates circular depressions around date palm tree trunks with a diameter varying between 1.0 m for the young trees and 3.0 m for the mature trees. The circular depressions are connected to concrete or an earth ditch or fed from the head ditch or a pipe (Fig. 8b). Then irrigation water is delivered to the individual circles through small checks from the head ditch or pipeline network. This method received more acceptance than raising bed planting in date palm irrigation because it subjects less surface area to water losses via evaporation.

4.2.3 Date Strip Irrigation (Albwaki)

In this method, the field is subdivided into rectangular strips set with different lengths and widths ranging from 4 to 6 m. Then, a strip is planted with young date palm trees in regular dimensional rows, and the adjacent strip is left without planting (Fig. 8c). Therefore, due to this method, the irrigated area was reduced by 50% (Al-Taher 2015) and consequently, the loss of irrigation water by evaporation was minimized.

4.3 Modern Pressurized Irrigation Systems

In the KSA, using scarce water resources is vital for agricultural development and sustainability (Al-Omran et al. 2021). Thus, adopting modern pressurized micro-irrigation systems and improving the physical properties of sandy soils are necessary for enhancing crop water use efficiency and economic return. Drip, sprinkler, and bubbler irrigation systems are water conservation techniques that reduce excessive on-farm applied water; therefore, they are important for water and food security in the KSA (Al-Ghobari and Mohammad 2011). Sprinkler irrigation saves about 42% compared to conventional surface irrigation methods, while drip irrigation saves about 70% (Al-Ibrahim 1990; Kaur et al. 2020). Accordingly, the irrigation application efficiency of the micro-irrigation systems ranged from 90 to 95%. It was about 70% for the sprinkler, and the surface irrigation method ranged from 45 to 60% (Phocaides 2000; Attri et al. 2022).

4.4 Micro-Irrigation

Micro-irrigation has advantages over traditional irrigation by automating and applying the needed irrigation water and fertilizer at the crop's root zone, decreasing weed and pest infestation, and lowering the operation cost (Madramootoo and Morrison 2013). Micro-irrigation methods include drip, spray, bubbles, and hose-basin application techniques (Kaur et al. 2020). Micro-irrigation is a pressurized irrigation system that utilizes pumps to deliver water under low pressure ranging between 10 and 3 bars. It can be done by sets of mains, sub mains and lateral lines directly to an individual plant or a tree where the water is distributed through an emitter for a plant or more emitters for a tree. However, clogging and mitigation of emitters can encounter their operation related to quality (Capra and Sciolone 2001). Hence, irrigators favour large-sized emitters to avoid clogging.

4.4.1 Sprinkler Irrigation System

Ten major sprinkler irrigation types can be grouped into fixed and portable sprinkler irrigation systems. A centre-pivot system has a moving lateral fixed at one end, and from sprinklers, sprinkles water to irrigate a large circular area. The centre-pivot system is the most adopted sprinkler irrigation type in the KSA. In the past thirty years, vast areas of the KSA desert land have been converted into productive irrigated farms (Al-Ghobari 2014). For example, in 1995, the Kingdom imported about 20,028 centre-pivot systems to irrigate wheat and forage crops. Such large numbers of pivots enhanced the intensive extraction of non-renewable fossil water for forage and wheat irrigation with almost zero recharge.

Consequently, the groundwater levels of principal confined aquifers in the KSA decreased annually by 1–2 m (MEWA 2020). However, in 2016, the authorities banned wheat production and restricted areas for green forage production. Henceforth, most centre-pivot systems were diverted to irrigate vegetable crops such as melons and potatoes. Compared to the conventional methods of irrigation, centre pivot irrigation uses less labour, reduces soil tillage, and lessens runoff and soil erosion.

4.4.2 Bubbler Irrigation System

Each bubbler of the bubbler irrigation system has a high discharge flow rate of about 7.6 L per minute; therefore, it is used to irrigate trees (Fig. 9a). This high discharge allows for shorter irrigation duration. The MEWA recommends using bubblers in date palm orchards and encourages the adoption of pressurized irrigation systems in place of traditional surface irrigation methods. The area irrigated by the bubbler irrigation method is a fraction of that irrigated by the conventional method. Thus it reduces the intensity of water losses caused by evaporation and deep percolation. However, bubblers are sensitive to debris in irrigation water but much less susceptible than the emitters of drip irrigation systems.

4.4.3 Free Flow Pipe Irrigation System

It is a simple irrigation method to supply water around a tree trunk. The SIO developed this tailor-made emission device that consists of a PE tube of 13 mm diameter ending

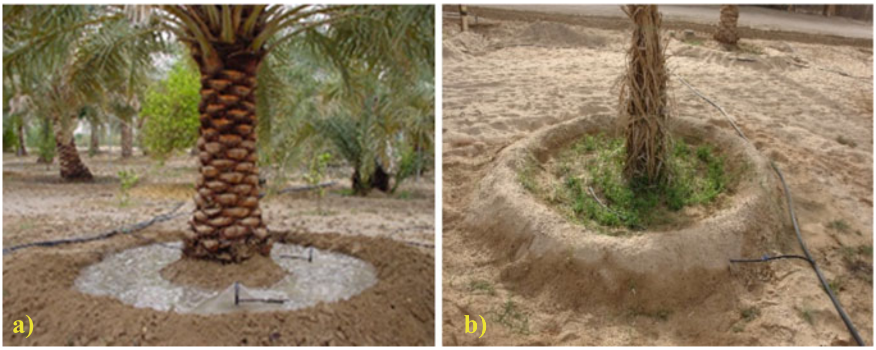

Fig. 9 Micro-irrigation systems. **a** Bubblers irrigation; **b** Free flow pipe irrigation. *Source* Water Studies Center, KFU, 2010

with a gate valve, as shown in Fig. 9b. This method can mitigate clogging when using drippers and bubblers and reduce the need for an expensive filtration module. The gate valve adjusts the flow required for a tree to achieve a high level of distribution uniformity. MEWA recommends such kind of irrigation method for both young and mature palm trees.

4.4.4 Drip Irrigation System

Sandy soils prevailed in most of the cultivated areas of the KSA. Therefore drip irrigation is an appropriate method of irrigation. There are two methods of drip irrigation, surface and subsurface, as shown in Fig. 10a, b. Drip irrigation methods, if designed and implanted properly, farmers could efficiently use water resources and enhance the water productivity of crops (Locascio 2005). Subsurface drip irrigation (SDI) is the most advanced method that applies water and nutrients 15–30 cm under the soil surface near plants' root zone for maximum crop benefits (Mali et al. 2017). Therefore, the SDI can maintain higher soil water content in the crop root zone and provide favourable conditions for improving plant growth. In addition, the SDI can reduce deep percolation and surface evaporation losses and minimize seasonal water usage (Montazar et al. 2017). The SDI has several significant advantages over the surface drip irrigation (DI) method, such as increased yield, reduced applied water and improved water productivity (Zeineldin and Al-Molhim 2021; Ayars et al. 2015). Drip irrigation methods use around 35% of the water consumed by surface irrigation methods. This was based on an on-farm evaluation, giving high water use efficiency (Maisiri et al. 2005).

Fig. 10 Drip irrigation systems. **a** Surface drip irrigation; **b** Subsurface drip irrigation. *Source* Water Studies Center, KFU, 2021

4.4.5 Traditional Irrigation Systems

Modern irrigation methods such as water-saving techniques, improvement of soil properties, and deficit irrigation are viable options for increasing water use efficiency and conserving scarce water resources of the KSA compared to traditional surface irrigation methods (Al-Zaidi et al. 2014; Al-Omran et al. 2021). Modern irrigation technology focuses on controlling water to reach the best use of water and labour and mitigate the dangers of waterlogging or salting. The gradual shift towards improved surface irrigation methods and then to modern pressurized irrigation systems was observed all over the agricultural regions of the KSA. For example, a study at Tabuk in the northwest region of the KSA indicated the positive attitudes of farmers toward adopting modern irrigation instead of traditional surface irrigation methods (Al-Zaidi et al. 2014). Based on the Aquastat survey of 2008, the FAO showed modern irrigation methods in the Kingdom covered about 66%, while conventional irrigation methods were employed in the remaining 34% of the irrigated area (FAO 2009). Table 4 shows the distribution per cent of traditional and modern irrigation across the thirteen agricultural regions of the KSA. The survey revealed that the largest irrigated areas are in Riyadh, Al-Qasim, Jizan, Hail, Eastern, and Al Jawf. In the Al-Qasim area, the central part of the KSA, more than one-third of the farmers (38.3%) employed traditional flood irrigation methods (Al-Subaiee et al. 2013) in date palm irrigation.

4.5 Water Security

The water and food security in the Middle East region is generally affected by climate change, water deficit, population increase, urbanisation development, and political problems (Hameed et al. 2019). Therefore, to fill gaps in the water supply, extensive

Table 4 Regional irrigated areas by traditional and modern irrigation methods

	Traditional irrigation		Modern irrigation		Total	
Region	Area (ha)	%	Area (ha)	%	Area (ha)	%
Riyadh	43,010	15	243,275	85	286,285	24
Mecca	43,924	98	1032	2	44,956	4
Al-Medina	26,618	93	2020	7	28,638	2
Al-Qasim	15,541	7	208,712	93	224,253	19
Eastern	16,081	15	92,987	85	109,068	9
Asir	22,232	99	296	1	22,528	2
Tabuk	5113	11	42,057	89	47,170	4
Hail	12,368	10	116,139	90	128,507	11
Northern	19	14	114	86	133	0
Jizan	177,375	99	1995	1	179,370	15
Najran	8811	68	4008	31	12,819	1
Al Bahah	2658	98	55	2	2713	0
Al Jawf	11,688	11	93,224	89	104,912	9
Total	385,438	32	805,913	68	1,191,351	100

Source FAO (2008)

energy is consumed for water desalination and wastewater recycling in the KSA (McDonnell 2014).

KSA highly depends on the groundwater resources found in the different aquifer formations that serve for crop production and domestic and industrial usage (Oumar et al. 2015). While the country is endowed with 2360 BCM of nonrenewable groundwater; however, only 1180 BCM is extractable, 50% (MEWA 2018). The over-extraction, especially for agricultural activity, and the negligible recharge rates have initialised severe concerns towards the KSA water security (National Water Strategy 2016).

Thus, water security faces fundamental challenges, including declining freshwater, water quality deterioration, climate change, non-beneficial water losses and poor water use efficiency in the KSA (Hameed et al. 2019).

The Kingdom's population rapidly increased, from around 4 million in 1960 to 32.5 million in 2018, and is projected to grow by 77% by the year 2050 (Baig et al. 2020; Rambo et al. 2017). This situation made the country incapable of meeting its agricultural water demands and investing heavily in desalination to meet the potable water-increasing needs (Baig et al. 2020; Palanichamy et al. 2018). As a result, water consumption rates in KSA's agricultural and urban sectors are considered wasteful (MEWA 2018). Furthermore, the lack of a tariff policy on extracted water from wells for agricultural purposes resulted in quantitative depletion and qualitative deterioration of groundwater, which have jeopardised water and food security in the KSA (Baig et al. 2020).

Despite the rapid population increase in urbanised areas and improving living quality, the KSA ensures its long-term water security for potable water by desalination (Lovelle 2015). Furthermore, seawater desalination is suggested as a sustainable solution for water scarcity in Saudi Arabia by employing renewable energy (Gujral et al. 2018).

However, if urbanisation growth outpaces the sustainable growth rate, the KSA will undergo a heightened threat to water and food security. Therefore, managing the demand and supply of water with the unprecedented population growth is a critical challenge for the KSA water security in the future. Therefore, there is a crucial need for behaviour changes to encourage water conservation and efficient water practices in agricultural, municipal and industrial usage sectors.

4.6 Policies and Legislation to Water Use in Agriculture

Water conservation and sustainability are the most critical components for overcoming water scarcity in KSA. However, according to the MEWA report of 2018, the rate of water consumption in the urban and agricultural sectors could have been more economically reasonable.

The KSA has started to formulate policies and strategies that regulate water use. The KSA started an agricultural policy for food self-sufficiency in the 1970s and achieved food self-sufficiency in many crops. Unfortunately, this policy resulted in the rapid depletion of groundwater. Later on, in 2008, the KSA introduced a new agricultural policy (Ouda 2014a). Accordingly, efforts were made to develop extensive, but efficient water conveys systems (Baig et al. 2020). Hence, the KSA's new policies restrict planting crops of high water consumption like wheat, barley and fodder. Also, the new policies encourage farmers to grow vegetable crops in greenhouses using water-saving technologies (Baig et al. 2017). As a result, the new policy has resulted in a noticeable reduction in irrigation water demand and the cultivated area of cereal crops. However, it needed to support the sustainable utilisation of groundwater resources (Ouda 2014a). The new policy has increased the importation of food crops to satisfy the country's demand (Multsch et al. 2017). However, this virtual water-dependent policy will save more water (Antonelli and Tamea 2015). Therefore, the virtual water trade is suggested to preserve water resources in KSA (Grindle et al. 2015). Trade-in virtual water can reduce water requirements in the agricultural and industrial sectors, allowing the exporters to achieve higher water productivity than importers (Odhiambo 2017).

The ministries council has approved the new water system act of the KSA, and it has been acting since the end of the year 2020 (MEWA 2020). It is a comprehensive new system that contains 77 articles. The system aims at preserving, developing, and protecting water resources, ensuring their sustainability and management. Also, it aims to regulate the water resources affairs, the rights related to them, and their uses, enhance the private sector's participation in the water system's activities, and strengthen effective governance. The act gave the MEWA the right to install meters to measure the water flow from wells located in non-renewable aquifers. Moreover, the new water policy aims to control and regulate the amount of water consumption and rationalise its use. Also, the MEWA may consider charging a fee if water consumption exceeds a given water rationing.

Permit-based groundwater systems (PBGS) have become more dominant; because more powerful pumps, population increase, and economic development have driven demand for groundwater that often oversupply. The PBGS enable the water administration to allocate water to different uses ranging from domestic, agricultural, and industrial uses to environmental ones, such as sustaining wetlands and the base flow of rivers (Mechlem 2016). However, implementing the PBGS is not cost-effective, administratively challenging, and time-consuming, especially in countries with many small-scale users. Moreover, introducing the PBGS will likely only succeed if it is well-designed and tailored to the local context and administrative capacity (Mechlem 2016). Hence, water policies and strategies in KSA should address the allocation of agricultural water demand with crop market values and water conservation aspects (Odhiambo 2017).

4.7 Technologies for Improving Water Utilisation

Adopting modern irrigation technologies in KSA reached 66%, while traditional surface irrigation was 34% (Baig et al. 2020). Nevertheless, the irrigation efficiency is only 50% (Al-Omran et al. 2021). Hence, improving irrigation technology and implementing on-farm water management can enhance irrigation efficiency. Al-Ghobari and Dewidar (2018) reported that integrating deficit irrigation strategies into surface and subsurface drip irrigation can save water in KSA. They found that the most significant irrigation water use efficiencies were obtained from the subsurface and surface drip at 0.6 of the total irrigation supply compared to 1.0 and 0.8. They conclude that deficit irrigation strategies show specific advantages to irrigation water management with minimum effects on crop production and quality. Also, the subsurface irrigation (SSI) system positively impacted irrigation efficiency and enhanced fruit yield and quality of the date palms in the eastern region of KSA (Mohammed et al. 2020). Moreover, the SSI was combined with the smart irrigation scheduling system in the arid region of KSA by Al-Ghobari et al. (2016). They indicated that the smart water controllers significantly reduced the amount of applied water and increased crop yield.

The farmers can easily adopt auto-steer machinery and centre-pivot irrigation systems since it requires little training and skills. However, adoption is often limited to technologies that require further investment in learning, hiring external services and data analysis, like soil and plant moisture sensors and related software (García et al. 2020).

The role of remote sensing technology (RST) is increasing rapidly as a complementary source of information for water resources assessment and monitoring. It can, directly and indirectly, measure nearly all hydrological cycle components (Sheffield et al. 2018). Therefore, satellite remote sensing can play a vital role in filling the gaps and enhancing water resources management (WRM) in KSA. The applications of the RST for WRM include crop water use and stress, evapotranspiration, precipitation, waterlogging, reservoir mapping and infrastructure evaluation (Mahmoud and Alazba 2016; Madugundu et al. 2017; Elhag and Bahrawi 2017; Allbed et al. 2018; Turk et al. 2021).

Desalinated water technology (DWT) can grow many crops under KSA's greenhouse conditions. In addition, using solar desalination reduces the energy cost of producing low-salt concentration water (Hussain et al. 2019). As a result, KSA is one of the leading in the Arab world in DWT, producing more than 1.6 billion m^3 of desalinated water each year (Awaad et al. 2020).

Information and Communications Technologies (ICT) have recently been linked with the Internet of Things (IoT) to improve water management globally. Also, they are used to make the operations of water resources, distribution, and quality more efficient (Alshattnawi and Jordan 2017).

4.8 Water Prospects in Saudi Arabia

Water is vital to human needs and development in the Arabian Peninsula. However, Mazzoni et al. (2018) reported that by 2050 the Arabian Peninsula would experience severe water shortages that can reach 20% in Saudi Arabia to almost 190% in Yemen based on their current water budgets. Furthermore, the water resources availability and quality can affect the environment and economy of these states at local and regional scales (Drewes et al. 2012). Therefore, the KSA must establish water management plans integrating water-resource development and management (Odhiambo 2017).

Currently, the KSA water prospects are significantly reducing the annual extraction and instead reusing treated sewage water in the agriculture sector. Based on vision 2030, the country's water strategies have proposed an objective to reduce the annual extraction from 22 to 12 BCM and reuse treated sewage wastewater for irrigation (MEWA 2018). The national strategic water plan of the KSA is to conserve the groundwater of confined aquifers for municipal and industrial usage and achieve water security, in turn, food security. Moreover, the MEWA for achieving development and suitability in the agricultural sector has proposed new crop structures for the agricultural regions, excluding extensive water-demanding crops like alfalfa. Also, MEWA encourages farmers to adopt modern irrigation systems and edge new irrigation technologies like hydroponic and aquaculture production systems.

MEWA formulated and developed a unified framework for the water sector in KSA. The framework includes a comprehensive water strategy that links trends and directions, policies, regulations and practices in the water sector at the national level of the KSA. Also, the framework sets the principal objective of directing the key challenges and restructuring the water sector (MEWA 2020). The MEWA framework has several parts: stakeholder engagement, assessment of the current situation, water

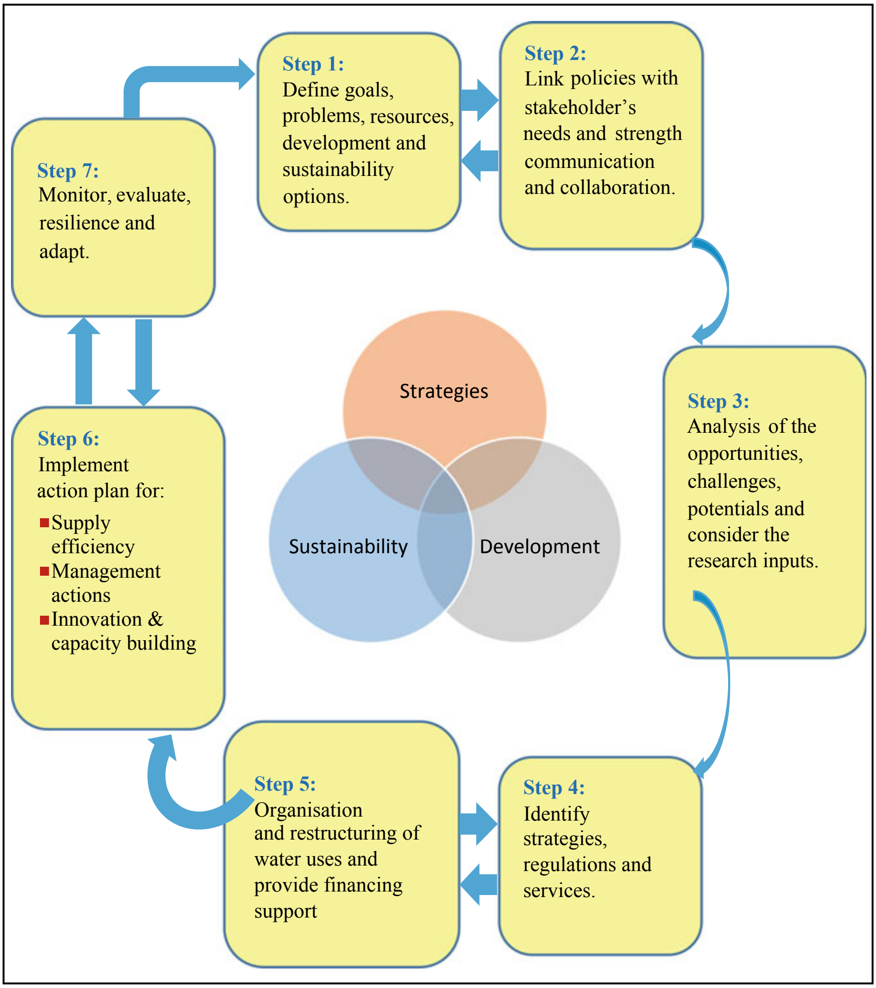

Fig. 11 A conceptual framework for water resources management in KSA. Adapted from MEWA (2020)

resources, sector operations, and facilities. Therefore, to make the MEWA framework more operational, a conceptual framework is suggested in this chapter to adjust the implementation process and consider future changes (Fig. 11).

The suggested conceptual framework can function as a tool that matches the MEWA strategies and policies with developing sustainable water resources. Hence, it defines the problems, aims, procedures, services, action plans, system monitoring, and adaption.

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Chapter 5
Domestic Food Production and Consumption in Saudi Arabia: Status Quo and Future Prospects

Ishtiag Faroug Abdalla

Abstract Nourished communities are recognized as having a productive and sustainable agricultural sector. The Saudi government has shown great concern for food production and availability, which is reflected in the Saudi Arabia Vision 2030 which focuses on both food availability and consumption. The overall objective of this chapter is to evaluate the current and potential status of domestic food production and consumption, as well as forecast patterns and changes in the future. In this chapter, time series secondary data and information gathered by the Food and Agriculture Organization (FAO) were used. The data covers crop and animal products from 1961 to 2021, as well as food supply information from 2010 to 2020. Data were analyzed using descriptive statistics such as averages, graphs, and trend lines. The results revealed that 43% of the land is used for fruit cultivation, 38% for cereals, and 18% for vegetables. The passage of time has had a significant effect on cultivated land and cropping patterns, which have changed significantly due to issues with water and natural resources. While the land and production for cereal crops are decreasing, they are increasing for vegetables. The increase in vegetable production is higher than the increase in land, attributable to advanced production technologies and efficient resource usage. Food supply showed changes over time, with varying self-sufficiency rates for vegetable crops ranging from 4 to 118% and fruits from 60 to 118%. For animal products, it ranged between 43% for red meat and 121% for milk. We conclude that despite the unfavorable climate and natural resource constraints to food production, efforts have been made to enhance production and food security regarding food availability in Saudi Arabia.

Keywords Animal product · Cereals production · Consumption · Food availability · Food security · Production · Saudi Arabia

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1 Introduction

Nourished communities are recognized as having a productive and sustainable agricultural sector. Agricultural activity is essential for every community, where a productive agriculture sector that is ecologically and socially sustainable is crucial for enhancing and improving human health and life (Sobaih 2023; Jones and Ejeta 2016). Saudi Arabia has shown great concern for food production and availability, which is reflected in Saudi Arabia vision 2030 which considers both food availability and consumption (Alnasser and Musallat 2022; Grindle et al. 2015). The growth of population and global climate and environmental changes require the authorities of each country to consider future food availability and accessibility. Haque and Khan (2020) and Pickson et al. (2023) have indicated that food production in Saudi Arabia is constrained by the weather, where temperatures are high and have been increasing over the years. This aligns with Fiaz et al. (2018), who noted that Saudi Arabia is mostly a food importer due to desert domination. Haque and Khan (2020) have also indicated that, despite the limited natural resources, Saudi Arabia is food secure as it is financially able to import food. Food and Agriculture Organization, FAO et al. (2021) refer to Saudi as a net importer of wheat, which is estimated to amount to around 80% of the country's needs. However, despite this, Saudi Arabia ranks among the top food wasters at the retail and household level, with 427 kg of food waste per capita per year (Baig et al.2019; Sobaih 2023). Alshabanat et al. (2021) estimated that food waste and losses in Saudi Arabia amount to about 33.1%. In line with Saudi Arabia vision 2030, which aims to address the issue of food security through four food security pillars, namely food availability, access to food, food utilization, and food stability, as identified by the UN Committee on World Food Security (CFS) (2014). Saudi Arabia's action plan is to enhance the resilience of food production, support food security and production in the country, and reduce dependency on imports. The government has allocated 665 million USD to support farmers (Arab News 2020). Saudi Arabia is also encouraging overseas agricultural investments, with Saudi investors acquiring agricultural land in foreign countries for crop and animal production. The government is supporting and boosting farming abroad in ten countries in Africa, the Black Sea, and Latin America by offering low-interest loans totaling 533 33 million USD to companies that send at least half their harvest to Saudi Arabia (Abu-Nasr and De Sousa 2020; Arab News 2020; FAO et al. 2021).

Economist Impact (2021) with the support of the Fondazione Barilla developed a measurement for the sustainability of food systems in 78 countries using the Food Sustainability Index (FSI). FSI is based on three key pillars mainly are food loss and waste, agriculture, and nutritional challenges. The Index consists of 38 indicators with 95 sub-indicators. The overall score is calculated from the scores of the three pillars. Saudi Arabia in 2021 scored 60 and ranked Medium (48 out of 78 countries), which reflects an average rank in terms of progress towards meeting environmental, societal, and economic indicators of food sustainability (Economist Impact 2021).

The major crops cultivated in Saudi Arabia are wheat, sorghum, barley, millets, dates, vegetables, and citrus fruits (Haque and Khan 2020). The agricultural production heavily relies on irrigation systems, which has a significant impact on freshwater aquifers, resulting in high production costs (Frenken 2009; Procházka et al. 2018). Due to the vast areas and varying climates in Saudi Arabia, cropping systems and patterns vary accordingly. However, climate change, particularly changes in temperature, annual rainfall, and water scarcity, is expected to cause a decline in crop production and alter the crop pattern (Mahmoud and Abdallh 2013). As a result, farmers are advised to shift from water-intensive crops to those with lower water requirements. The objective of this chapter is to evaluate the current and potential status of domestic food production and consumption, as well as forecast patterns and changes in the future.

2 Methodology

This chapter relies on secondary data and information that was gathered and analyzed to achieve the chapter's bjectives. Time series data regarding crop area, production, consumption, and self-sufficiency was collected from various sources, such as the Food and Agriculture Organization (FAO) website (FAOstat.org), the Gerneral Authority for Statistics in Saudi Arabia, the Ministry of Environment, Water, and Agriculture (MEWA), and other related publications. The data collected covered the time period from 1961 to 2021 for cereal crops (sorghum, wheat, barley, maize, and millet), vegetable crops (potatoes, tomatoes, and onions), and fruits (dates, citrus, and watermelon). Animal production data, such as eggs and red and poultry meat, was also gathered. Consumption data for some cereals, vegetables, fruits, and animal products were obtained from the Ministry of Statistics for the year 2021 and from FAO from 2010 to 2020. Simple calculations as simple descriptive and trend line analysis were performed.

3 Findings

3.1 Domestic Food Production: Current Status and Potential

The total area of Saudi Arabia is estimated to be about 2240 thousand km^2, with the agricultural area being about 173.6 thousand km, or about 8.1% of the total area. Crops grown in Saudi Arabia included cereals, vegetables, fruits, and fodder. Adam et al. (2014) reveal that cereals cover about two-third of the cultivated area while vegetable and fruits cover one-third.

Table 1 Area under cultivation, and crop and livestock production in Saudi Arabia for the year 2021

Item	Area (000 ha)	Production (000 mt)	Available for consumption (000 mt)	% of self-sufficiency
Plant product				
Cereals	188.8	881.7	–	–
Fruit	213.1	2474.1	–	–
Vegetable	92.8	2305.4	–	–
Vegetable (greenhouse)	6.0	613.6	–	–
Fodder	210.0	3870.1	–	–
All	*710.8*	*10,144.9*	–	–
Livestock product[a]				
Red meat		178.0	414.0	43
Eggs		359.2	321.0	112
Poultry meat		930.0	1409.0	66
Fish meat		177,264	344,601	51
Milk		2600.0	2149.0	121

[a] Compiled by the author based on the data from MEWA (2021a)

Table 1 displays the cropped areas (000 ha) and production (000 mt) of different crop groups and livestock products in Saudi Arabia in 2021. The total cultivated area is estimated to be approximately 710 thousand ha, used for growing cereals, vegetables, fruits and fodder crops. Fruits and fodder are grown on approximately 30% of this land each. However, domestic production of poultry meat, red meat, and fish falls short of domestic demand. On the other hand, domestic production of eggs and milk exceeds domestic demand.

Figure 1 shows the share of cultivated areas for vegetables, cereals, and fruits in Saudi Arabia in 2021. Fruits cover about 43% of the cultivated area, followed by cereals at 38% and vegetables at 19%.

3.1.1 Cereals Production

Wheat, sorghum, barley, and millet are the main cereals grown in Saudi Arabia. Rice used to be grown in Saudi Arabia from 1961 to 1980, with an average area of about 616 ha producing about 1634 mt, but it was discontinued due to the high water requirements. Figure 2 shows the total cereals area in Saudi Arabia. The area increased during the 1980s and 1990s but later declined. As shown in Fig. 2, the trend line of the area during the time did not explain much, and its contribution to affecting the change in the area is small. This could be explained by climate and resource availability constraints. On the other hand, the effect of time is significant on cereal production ($F = 13.35^{***}$), which could be attributed to advances in agricultural

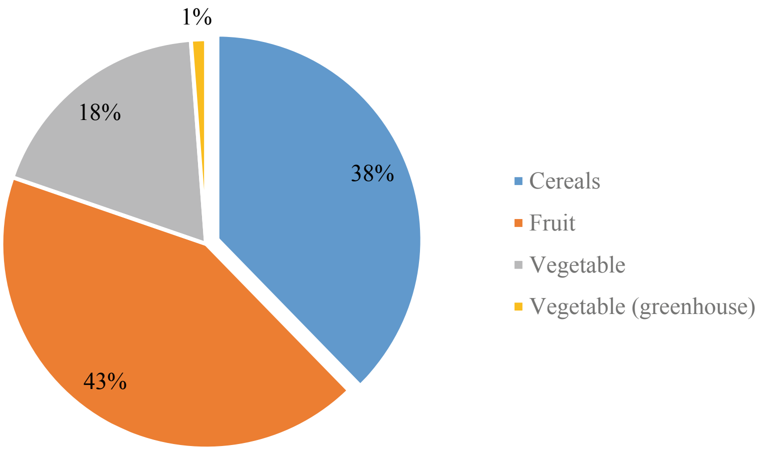

Fig. 1 Shares of the cultivated land in Saudi Arabia for the year 2021. *Source* Prepared by the author based on data from MEWA (2021a)

production technologies. Figures 3, 4, and 5 show wheat, barley, and millet production (in mt) from 1961 to 2021. Production was boosted during the 1980s for cereals due to area expansion and an increase in the average yield. For example, wheat and barley areas were boosted during the 1980s and 1990s, resulting in surpluses and even exports. Later, due to scarce and non-renewable water resources and the need to control water demand, the area declined significantly. These results indicate what Mahmoud and Abdallh (2013) and Haque and Khan (2020) have also observed. FAO et al. (2021) has also specified that intensive wheat farming is depleting freshwater aquifers, highlighting the priorities of resilience policies.

Figure 5 shows millet production, which increased during the 1960s and then decreased after 1972 up to the present day. The production has stayed consistent, ranging from 7 to 12 thousand mt. The trend line shows a decrease of − 1.2 thousand mt annually in millet production.

3.1.2 Vegetable Crops

Many vegetable crops are grown in Saudi Arabia, including potatoes, tomatoes, onions, cucumbers, and gherkins. The area and production from 1961 to 2021 are represented in Table 2 and Figs. 6, 7, 8, 9, 10 and 11. Table 2 shows the equation for the trendline of the areas and production of potatoes, tomatoes, onions, cucumbers and gherkins in Saudi Arabia from 1961 to 2021.

Figures 6 and 7 depict the areas (in thousands of hectares) and production (in thousands of mt) of potatoes and tomatoes between the years 1961 and 2021. The tomato area experienced a surge from the 1970s to the 1990s followed by a decrease, while the potato area has been on the rise since the 1990s. Time appears to have

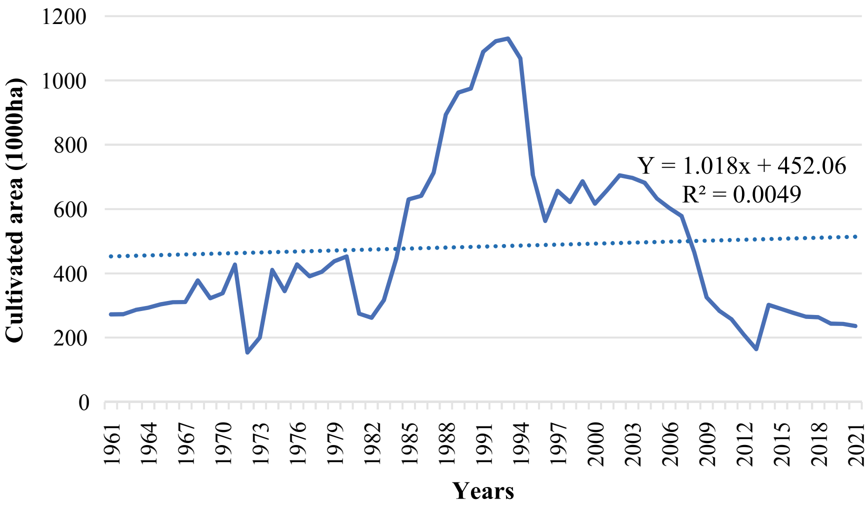

Fig. 2 The cultivated area for cereals in Saudi Arabia between 1961 and 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

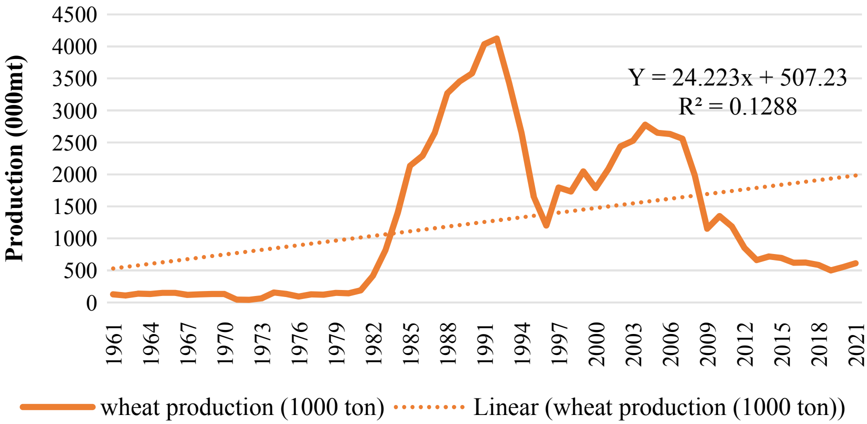

Fig. 3 Wheat production (000 mt) in Saudi Arabia from 1961 to 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

had a significant impact on potato area ($R^2 = 82\%$) compared to tomato area ($R^2 = 11\%$). Figure 7 shows that tomato production increased over time, from 1961 to 2021 ($R^2 = 65\%$). Despite the tomato area declining in the 2020s, the production remained stable, which could be attributed to an increase in yield and the rise of greenhouses production. Potato production has been stable, similarly to the area, which has experienced growth since the 1990s. The effect of time on production changes can be explained by $R^2 = 84\%$. The figures showing the area and production

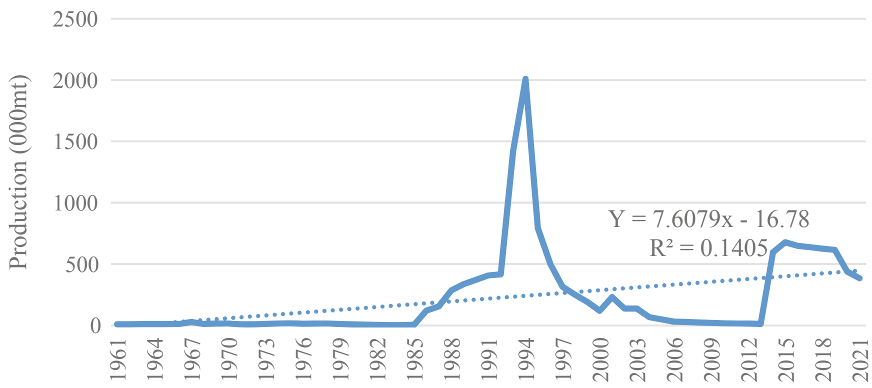

Fig. 4 Barley production (000 mt) in Saudi Arabia from 1961 to 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

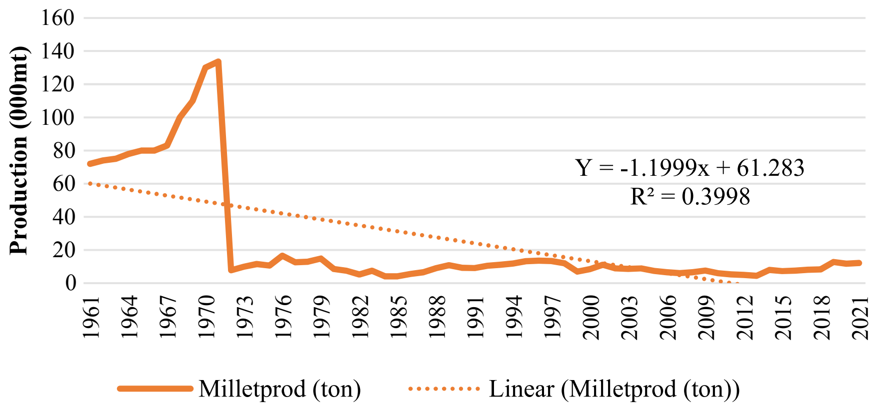

Fig. 5 Millet production (000 mt) in Saudi Arabia from 1961 to 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

Table 2 Equations for the trendlines of the area and production of some vegetable crops

Crop (Y)	Duration	Function	R^2
Tomato area (ha)	1961–2021	123.2x + 12,158	0.106
Tomato production (mt)		7442.6x + 86,454	0.653
Potato area (ha)	1961–2021	423.5x − 4663	0.825
Potato production (mt)		10,508x − 129,413	0.841
Onion and shallots area (ha)	1961–2021	36.263x + 2626.9	0.0384
Onion and shallots production (mt)		1881.3x + 10,732	0.258
Cucumber and gherkins area (ha)	1978–2021	18.183x + 2713.4	0.033
Cucumber and gherkins production (mt)		4184.1x + 39,446	0.427

Source Prepared by the author based on data from FAOstat.org (2021)

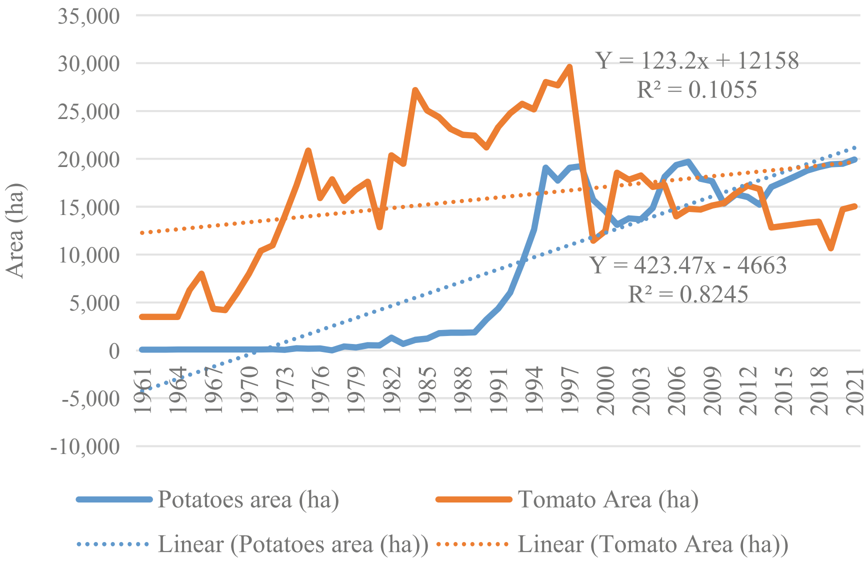

Fig. 6 The cultivated area for tomatoes and potatoes (ha) in Saudi Arabia between 1961 and 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

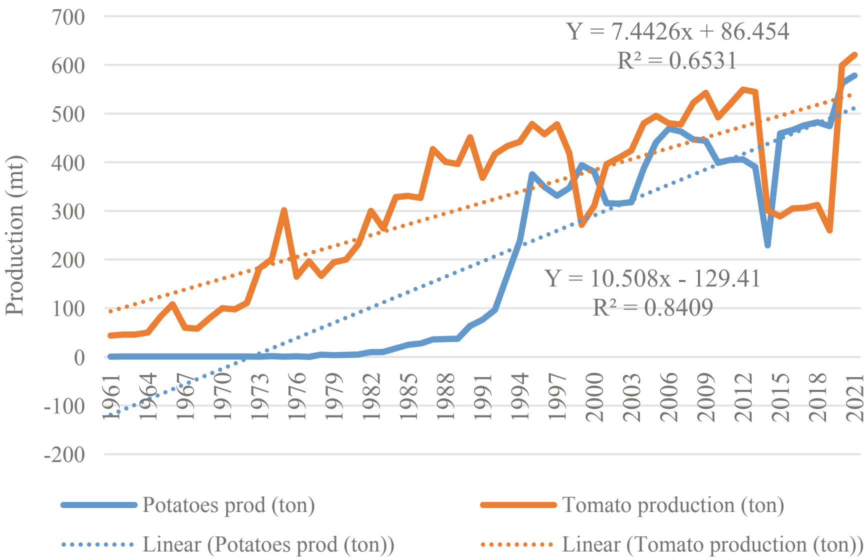

Fig. 7 Tomato and potato production (000 mt) in Saudi Arabia from 1961 to 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

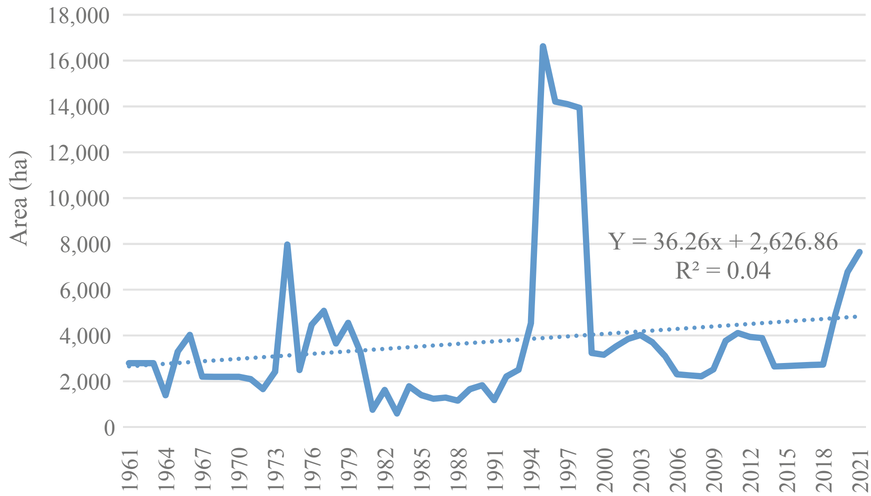

Fig. 8 The cultivated area for onion (ha) in Saudi Arabia between 1961 and 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

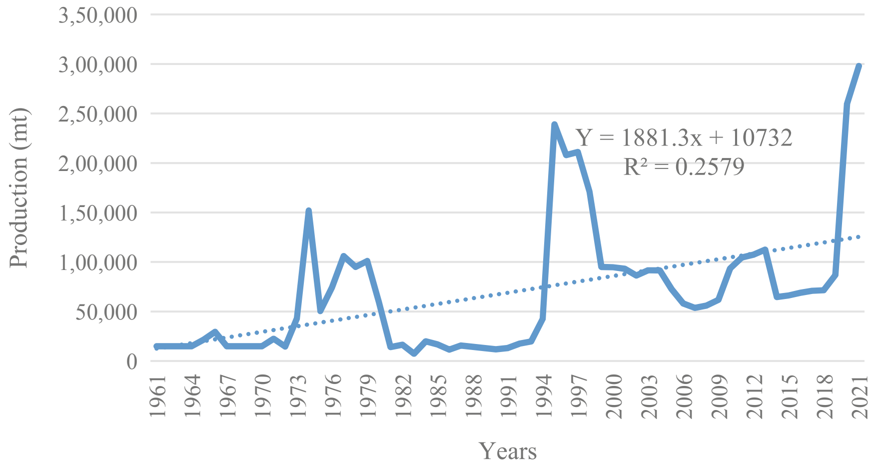

Fig. 9 Onion production (mt) in Saudi Arabia from 1961 to 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

of onions and shallots are presented in Figs. 8 and 9. The area and production of onions experienced a boost during the 1990s, followed by a decline in the early 2000s. However, in the 2020s, the production begins to rise once again. The effect of time on area ($R^2 = 38\%$) is greater than its effect on production ($R^2 = 25\%$). Data on cucumber and gherkins' area and production are available from 1978 to 2021, showing that the increase in production has been more significant than that in area

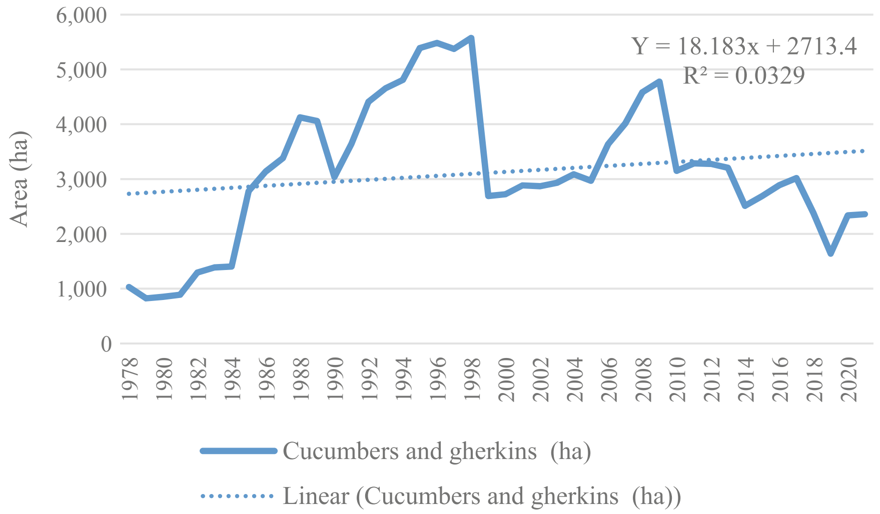

Fig. 10 The cultivated area for cucumber and gherkins (ha) in Saudi Arabia between 1978 and 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

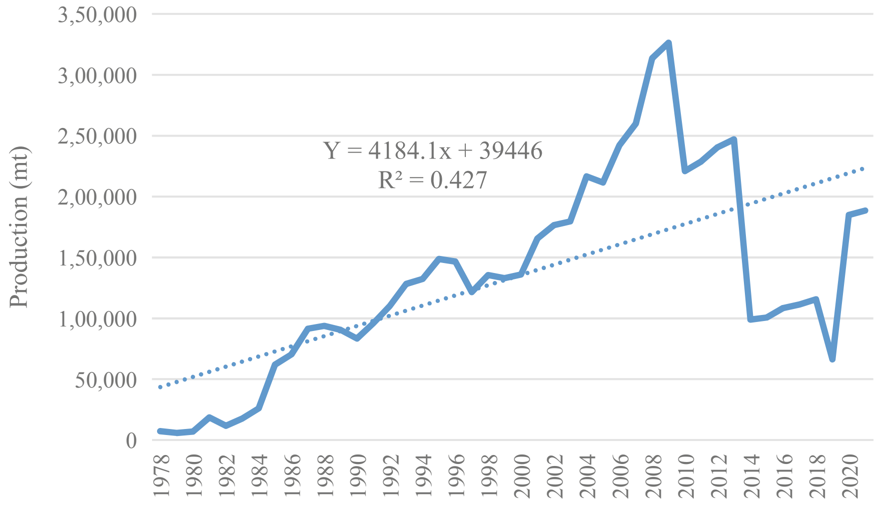

Fig. 11 Cucumber and gherkins production (mt) in Saudi Arabia from 1978 to 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

(Figs. 10 and 11). The time effect on production was higher ($R^2 = 43\%$) than on the area ($R^2 = 3.3\%$), with the growth partially explained by the adoption of production technologies (Alotaibi and Kassem 2021).

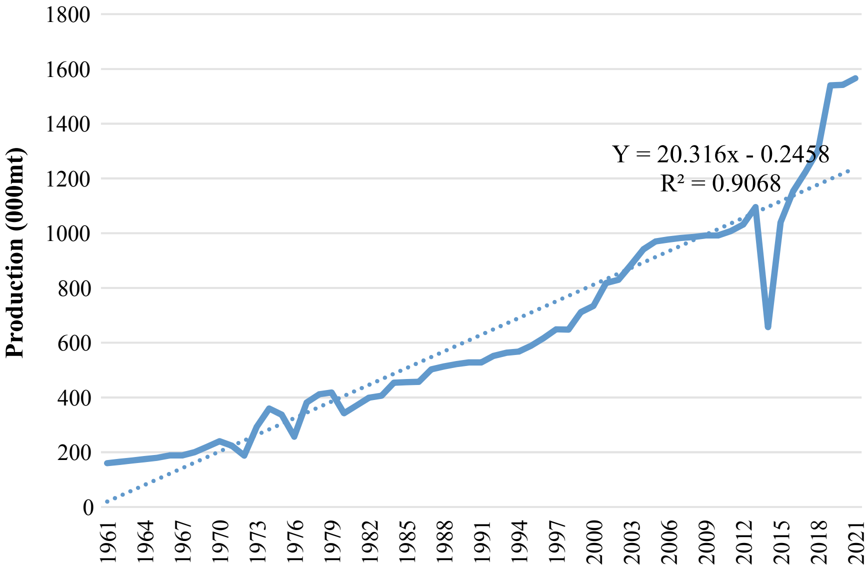

Fig. 12 Date production (000 mt) in Saudi Arabia from 1961 to 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

3.1.3 Fruits Production

Various fruit crops are cultivated in Saudi Arabia, including dates, grapes, citrus, and watermelon. The climate, environment, and culture of the region are favorable for the cultivation and production of dates. Figure 12 shows a significant increase in date production from less than 200 thousand mt in 1961 to 1600 thousand mt in 2021. The time factor alone accounts for 90% of this change. Figures 13 and 14 provide information on the area and production of citrus from 1961 to 2021. Citrus cultivation area and production increased during the 1970s, declined in the 1980s, rose again until 2009, before declining steadily between 2010 and 2015 and stabilizing thereafter. Finally, Figs. 15 and 16 depict the area and production of watermelons in Saudi Arabia over the same period. Both demonstrate an increasing trend over time. The time factor alone explains 52% of the change in area and 27% of the change in production.

3.1.4 Livestock Product

Saudi Arabia, being a desert climate country, primarily raises camels, cattle, sheep, goats, and poultry. Approximately 7.1% of the population works in the agricultural sector. The number of animals is represented in Fig. 17, indicating that goats surpass the others. The growth of animal populations is significantly influenced by time, as indicated by the trend lines in Figs. 15 and 17. The data displays that goats have

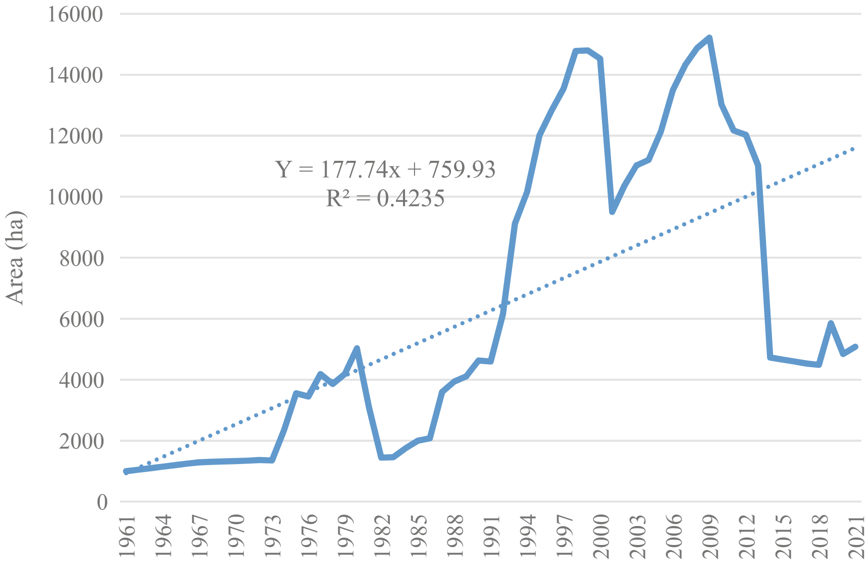

Fig. 13 The cultivated area for citrus (ha) in Saudi Arabia between 1961 and 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

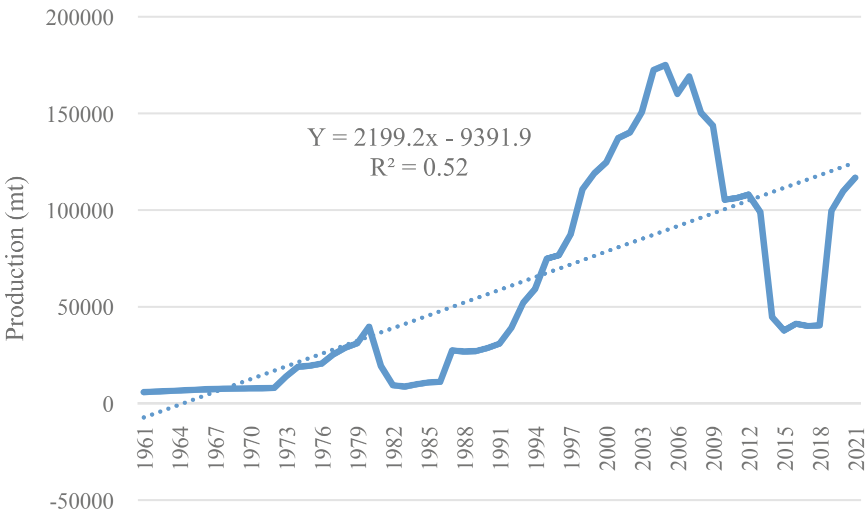

Fig. 14 Citrus production (mt) in Saudi Arabia from 1961 to 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

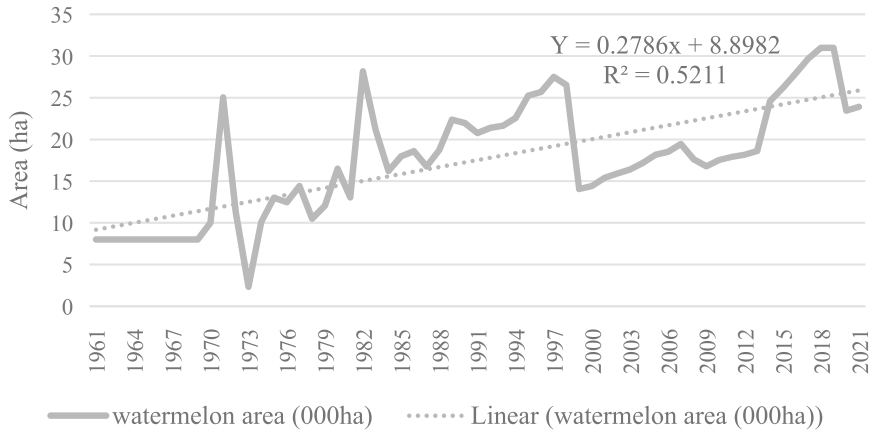

Fig. 15 The cultivated area for watermelon (000 ha) in Saudi Arabia between 1961 and 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

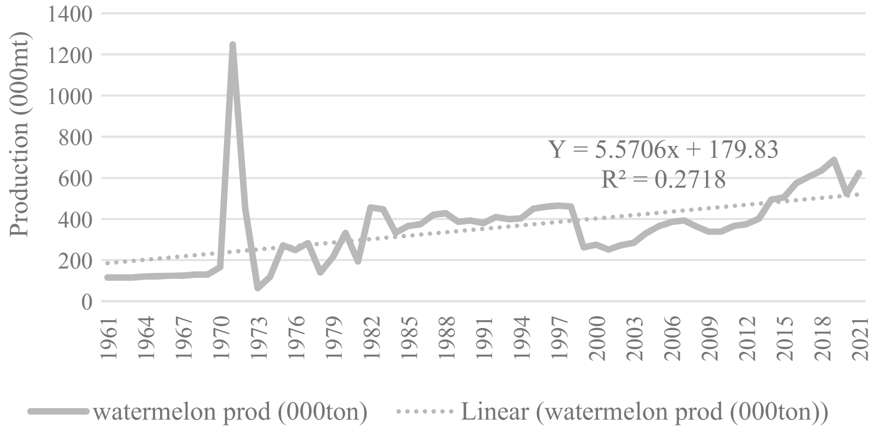

Fig. 16 Watermelon production (000 mt) in Saudi Arabia from 1961 to 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

an R^2 value of 75%, cattle 22%, camels 69%, and chickens 95%. Poultry, red meat, and eggs are the most coveted products in Saudi Arabia. The production of camel, sheep, and chicken meat from 1961 to 2021 is displayed in Figs. 17 and 18. Poultry meat production has witnessed substantial growth over time, which is reflective of high demand. Figure 19 demonstrates the milk production of camels, cattle, and goat animals from 1961 to 2021. Cattle milk production has shown remarkable growth along with a significant impact over time. The R^2 value is 80% for cattle, 82% for camel, and 77% for goat. Figure 20 exhibits an increase in egg production in Saudi

Arabia from 1961 to 2021. The trend line indicates annual growth in production exceeding that of the chicken population.

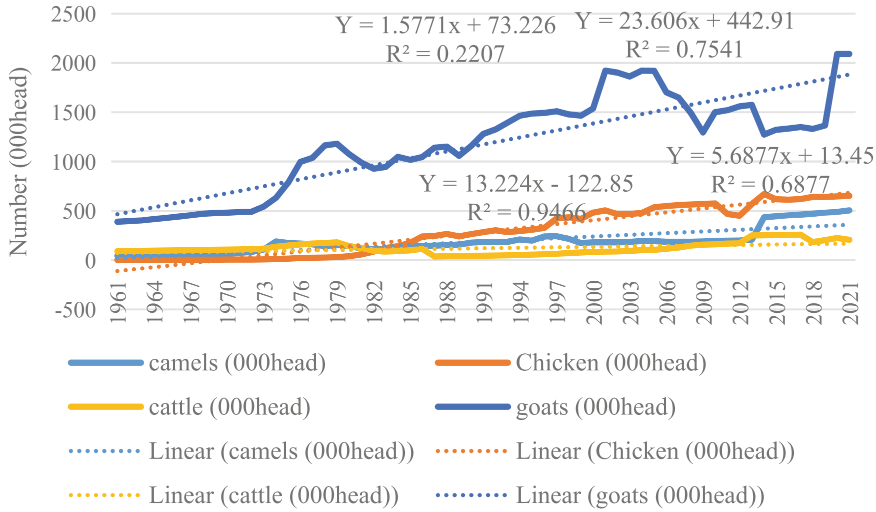

Fig. 17 Camel, cattle, goats and chicken number (000 head) in Saudi Arabia from 1961 to 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

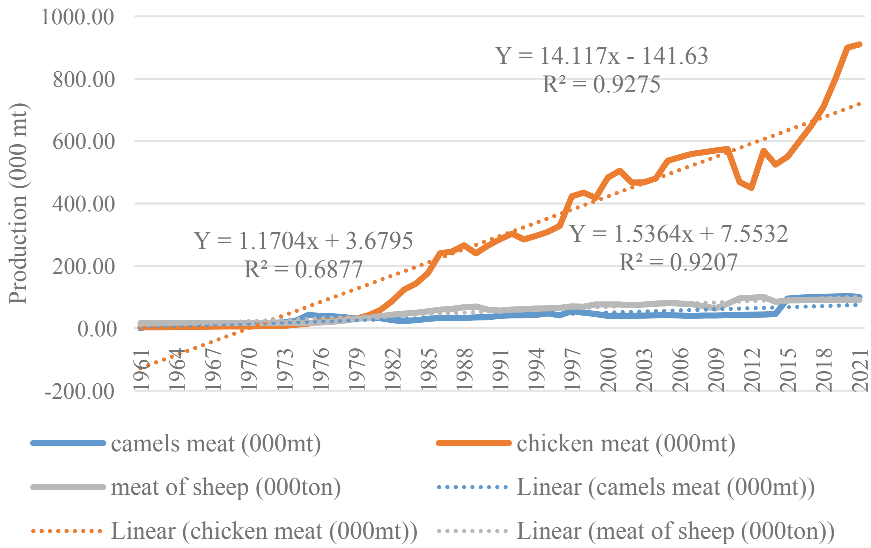

Fig. 18 Camel, sheep, and poultry meat production (000 mt) in Saudi Arabia from 1961 to 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

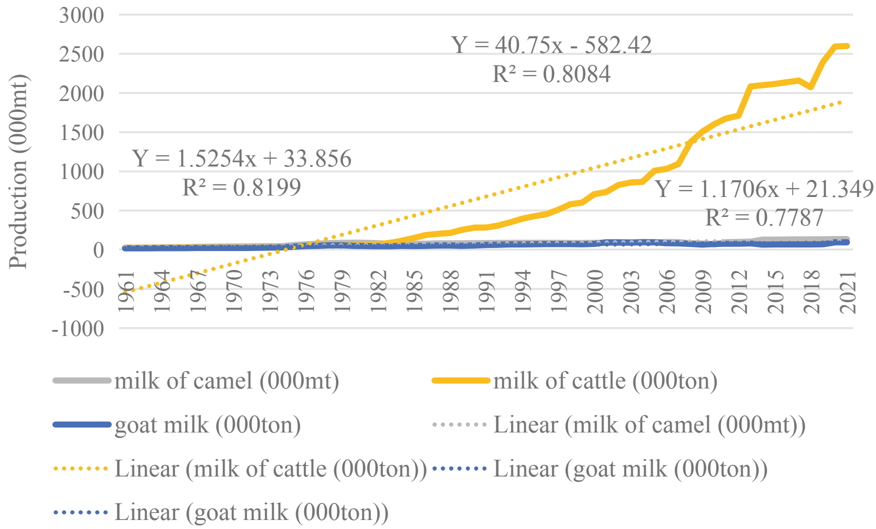

Fig. 19 Milk production of camel, cattle and goats (000 mt) in Saudi Arabia from 1961 to 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

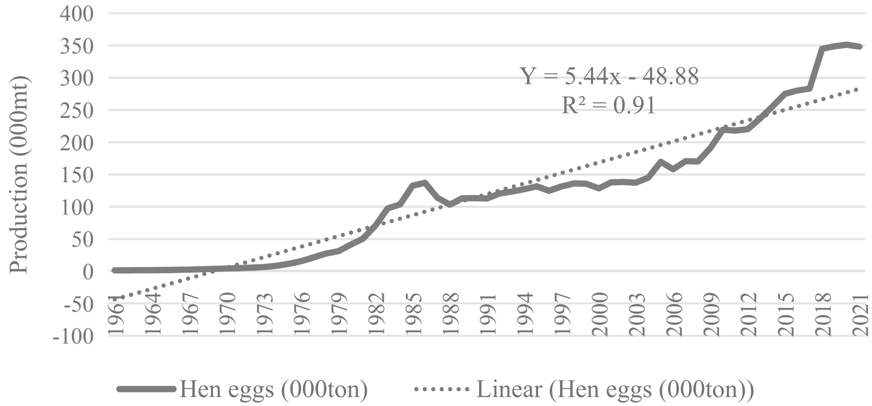

Fig. 20 Eggs production (000 mt) in Saudi Arabia from 1961 to 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

3.2 Aggregate Domestic Food Consumption

3.2.1 Food Security and Climate Change

Food security and climate change are important issues in the agriculture sector, which is a fast-growing industry in the country. Depending on natural resources and maximizing their efficient use will result in a better quality of life for individuals. The

Saudi Arabia government is committed to diversifying its business away from the sole reliance on oil exports and production. The agriculture sector contributes 54 billion SR annually to the GDP and provides 30% of the food available for consumption, however, the country relies heavily on imports (Haque and Khan 2020).

3.2.2 Food Security in Saudi Arabia

According to Guiné et al. (2021), Saudi Arabia is considered food secure based on the security pillars of food availability, access, utilization, and stability. As an oil-producing country, Saudi Arabia is able to import sufficient food. According to the Human Development Report (2021), Saudi Arabia is ranked 35th among high-income countries (UNDP 2022). However, as noted by Adam in 2014, there are still segments of the population in high-income countries like Saudi Arabia who do not have adequate nourishment. Fiaz et al. (2018) also highlight the obstacles in domestic food production due to limited agricultural resources. Table 3 shows the production, net consumption, and self-sufficiency rates for selected vegetable and fruit crops that were grown in Saudi Arabia in 2021. Taking into account production constraints, imports exceeded exports for all listed crops except for dates. The self-sufficiency rate ranged from 4 to 118%. For vegetable crops, it ranged between 116% for eggplant and 38% for carrots. Onions, tomatoes, and potatoes had self-sufficiency rates of 52%, 77%, and 92%, respectively. Among fruit crops, dates had the highest self-sufficiency rate of 118%, followed by citrus fruits at 99%, and mangoes and grapes at 60% each. Figure 21 represents the cereal dependency ratio from 2000–2002 to 2017–2019, which increased from 73 to 94%. The dependency is significantly related to the time factor. This reflects the increase in cereal imports. Wheat consumption showed highly significant growth ($R^2 = 94\%$) from 1978 to 2021 (Fig. 22). Animal products are the main source of protein globally. Meat production needs to be increased to cover population growth, as recommended by the World Bank (Alsarawi et al. 2022). Alsarawi (2022) revealed that the self-sufficiency ratio for red meat, poultry meat, and fish from 2005 to 2020 is changing with an average of about 57%, 50%, and 42%, respectively. Population growth increases the food gap in meat and animal products.

Table 4 shows the annual supply quantity (in kg) per capita consumption for selected food items. In general, the supply of selected food items changes annually, showing an increase and then a decrease, with the exception of wheat and eggs which are increasing. On average, there is approximately 96 kg of wheat and 55 kg of rice available for consumption. In comparison to the rest of the world, the per capita consumption of wheat and rice is higher, with the world consuming about 67 kg of wheat and 78.4 kg of rice per capita in 2018. The supply of poultry meat is higher than the world consumption. The annual supply of eggs is increasing and is almost near to the world consumption levels. The supply of milk, 47 kg/capita, is far below world (79 kg) and Asia (60 kg). The average per capita supply from fish, tomato and onion is almost equal the world supply and Asia supply per capita Potato annual per capita supply is ar below the world and Asia supply.

Table 3 Production, consumption and self-sufficiency in Saudi Arabia, 2021

Crop	Production (000 mt)	Imports (000 mt)	Exports (000 mt)	Consumption (000 mt)[a]	% of self sufficiency
Potato	578.1	48.3	0.0	626.3	92
Tomato	620.9	186.8	0.6	807.1	77
Onion	298.0	274.5	0.5	572.0	52
Squash	64.7	1.6	1.5	64.7	100
Gherkins	188.6	1.4	3.1	186.8	101
Sweet pepper	108.1	29.5	3.5	134.1	81
Okra	25.3	0.3	0.8	24.9	102
Carrot	24.5	43.7	3.8	64.4	38
Eggplant	112.0	0.8	6.4	106.4	106
Grapes	106.4	71.8	0.5	177.8	60
Dates	1565.8	19.8	258.1	1327.5	118
Watermelon	624.1	7.1	0.1	631.1	99
Citrus	116.8	657.9	10.4	764.3	15
Mango	88.7	60.0	0.9	147.8	60
Banana	22.2	496.7	5.4	513.4	4

Source MEWA statistical book 2021
[a] Author compilation

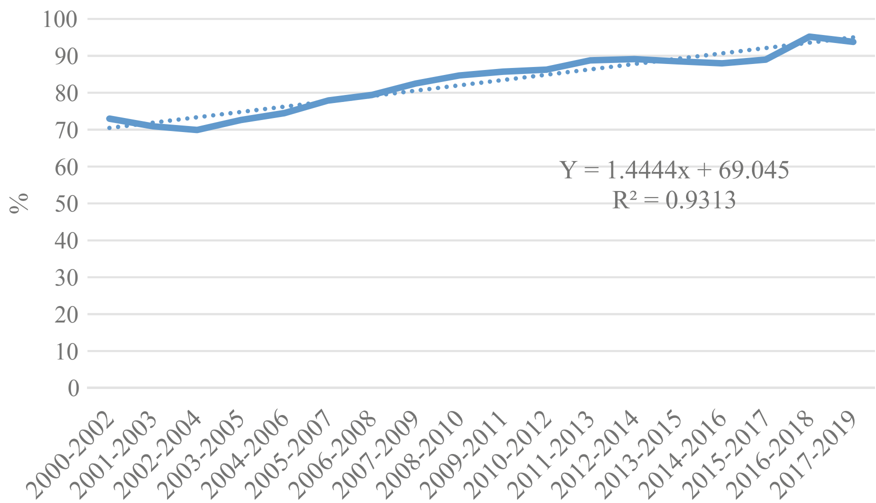

Fig. 21 Cereal imports dependency in Saudi Arabia from 2000–2020 to 2017–2019. *Source* Prepared by the author based on data from FAOstat.org (2021)

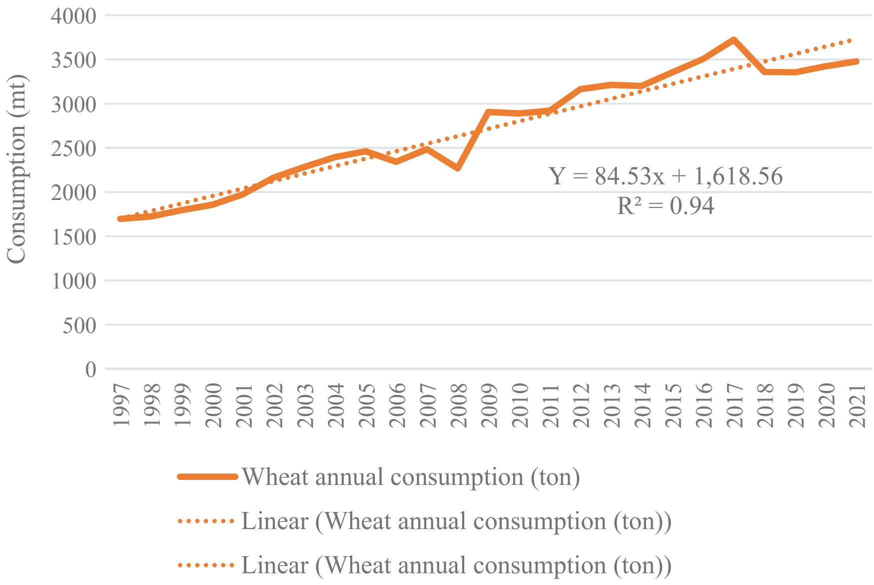

Fig. 22 Wheat consumption (mt) in Saudi Arabia from 1997 to 2021. *Source* Prepared by the author based on data from FAOstat.org (2021)

4 Future Prospects for Production and Consumption of Food Items

The IAEA (2018) reported that Saudi agricultural land is suffering from salinity due to various factors, including the extensive use of underground water, crops grown using chemical fertilizers and pesticides, and farming practices implemented by farmers. Effective farm management can greatly reduce the problem of salinity. Haque and Khan (2020) reported a significant increase in average temperature in the last 50 years, which has led to a significant decrease in crop yields. Fortunately, this has not led to a large change in rainfall. However, Procházka et al. (2018) noted that this has had a less significant effect on agricultural production in Saudi Arabia, which is mainly irrigated. He also projected that water demand will increase by 2030, which will require action. Overall, factors such as climate change, soil problems, chemical use, and water requirements are reducing the production and yield of food crops, which in turn affects the national food supply and security. This conclusion is in line with Avnery et al. (2011) report highlighting the increasing threat to global food security caused by O_3 pollution. Additionally, Fiaz et al. (2018) noted that due to the limitation of agricultural resources such as land and water, Saudi Arabia is expected to import all of its domestic needs by 2050. Al-Shayaa and colleagues (2020) indicated that the initiation of large-scale agriculture in Saudi Arabia requires

Table 4 Food supply quantity (kg/capita/yr) in Saudi Arabia from 2010 to 2020

Year	Wheat and products	Rice and products	Mutton and goat meat	Poultry meat	Bovine meat	Eggs	Milk	Fish	Potatoes and products	Tomato and products	Onions
2010	90.0	55.2	5.7	45.4	5.4	4.8	43.0	20.0	9.0	25.2	11.7
2011	86.5	54.3	6.2	44.2	5.4	4.9	47.2	20.2	10.01	24.6	12.1
2012	89.3	54.8	6.2	43.4	5.7	5.1	53.6	22.9	11.6	26.4	13.3
2013	89.4	53.9	6.5	48.9	5.6	5.2	42.5	22.6	18.0	23.9	12.9
2014	102.7	52.0	6.2	40.4	5.5	5.3	52.1	21.3	13.0	15.6	11.7
2015	98.9	59.0	5.9	43.3	5.4	6.7	43.4	20.4	13.2	16.1	13.1
2016	98.9	53.9	5.0	44.6	4.3	7.1	45.8	17.9	13.0	16.3	12.7
2017	99.9	52.6	4.9	38.0	4.8	6.8	45.0	19.0	16.2	15.3	13.3
2018	98.9	55.6	4.6	35.0	4.6	7.8	44.2	16.9	16.1	15.0	13.1
2019	100.4	53.6	4.3	41.2	4.3	8.7	46.8	15.6	17.1	17.0	10.6
2020	99.2	56.1	4.8	43.0	4.4	10.0	52.1	16.3	19.1	19.6	16.1
Average	95.8	54.6	5.5	42.5	5.0	6.6	46.9	19.4	14.2	19.6	12.8
Per capita consumption 2018[a]											
World	67	78.4	NA	15.6	9.1	9.7	79.3	20.2	32.9	21.2	11.8
Asia	65.2	113	NA	10.1	4.7	10.1	60.2	23.7	29.9	21.4	13.1

Source FAO: https://www.fao.org/faostat/en/#data/FBS
NA not available
[a] https://goodseedventures.com/worldwide-food-consumption-per-capita-2/

the government's continuous search for environmentally friendly farming practices. They also revealed that farmers are aware of these practices, but more effort is needed to encourage them to adopt and stay updated on good practices.

The global community has come up with an initiative called Good Agriculture Practice (GAP) to enhance food safety, as reported by the United Nations in 2019. This initiative aligns with the Sustainable Development Goals (SDGs) related to food safety. According to the United Nations, the aim of GAP is to eliminate food hazards, improve working conditions for farmers, and protect the environment. GAP brings together all parties involved in food production and distribution. Relevant institutions and adopters require certification for GAP. The Arab Organization for Agricultural Development (AOAD) adopted this practice in 2007 through the development of the ArabGAP guide to promote the adoption of GAP in the Arab world. Along with Saudi Vision 2030, which aims to enhance food security, the Saudi government highly prioritizes improving the quantity and quality of available food. In 2017, the MEWA established a plan to implement SaudiGAP, with a unit dedicated to guiding the plan and offering annual certification for those employed in the industry (MEWA 2021b; United Nations 2019).

Organic farming and advanced agricultural technologies are being encouraged in Saudi Arabia to increase food production and efficiently utilize the country's economic resources. MWEA (2021b) reflects a change in food production items for the years 2019–2021 in comparison to 2015. Vegetable production in greenhouses has increased by 127%, and fish from fish farms has increased by around 260% between 2015 and 2021. Saudi GAP has contributed to enhancing production and marketing efficiency in egg, chicken, and cow-raising farms since 2021. GAP in vegetables, field crops, and dates has significantly contributed to increasing production (760%) and the number of certified working farms (29%). Meanwhile, efforts to utilize scarce resources such as water have been emphasized by adopting water harvesting techniques and decreasing fodder land from 640 thousand ha in 2015 to 214 thousand ha in 2021.

Furthermore, it has been reported that efforts to develop food safety and organic farming have resulted in significant achievements such as a decrease in pesticide residuals from 24 to 4%, the incorporation of organic fertilizers in hydroponic farming has increased from 0 to 45%, and there has been a notable increase of approximately 100% in the production of organic food. According to MEWA (2021b), there has been a significant improvement in the services provided to farmers and other parties working in agriculture to enhance the performance of agricultural production, such as crop protection and animal vaccinations.

In regards to the forecasted estimates for crop production in the year 2030, Table 5 outlines select crops such as cereals, vegetables, fruits, and animal products. The results are based on trend lines estimated through Excel. Table 5 displays the production in 2021, the expected production in 2030, and the percentage change. Wheat and barley both show a positive increase of 36% and 34%, respectively, which may be due to intensive production during earlier years. Millet production showed negative production in 2030 which could be due to high decrease in production trend. Date production shows a decrease of 9%. Potato production is expected to increase by 4% from 2021 to 2030, while onion production is expected to decrease, which could be explained by annual changes in production. The expected animal production in 2030 shows variation. Hen egg and milk production are both expected to decrease by about 5% and 11%, respectively. However, sheep meat production is expected to increase by about 27%, while chicken and camel meat production are expected to increase by about 18% and 7%, respectively. Abdullah et al. (2016) studied the impact of agro-meteorological and socio-economic parameters such as water scarcity, CO_2 fertilization, and climatic change vulnerability on pasture yields and the resulting effects on meat production in 2030. The author revealed that these factors are expected to have a negative effect and could cause a substantial reduction in beef, mutton, and poultry production.

The growing population, changes in taste and preferences, and intensive production will put pressure on resources and the environment. Saudi consumers tend to favor meat due to social and cultural factors. In 2017, the average daily meat consumption among Saudis was 73.3 g. According to Adam et al. (2014), meat supply increased by 435% from 1990 to 2007. Saudi Arabia scored 58 on food loss and waste and ranked 37 out of 78 countries, indicating substantial food losses. The Ministry of Environment, Water, and Agriculture (MEWA) developed a set of initiatives to reduce food waste and promote sustainability, including a national program of food waste reduction (Alshuwaikhat and Mohammed 2017). Sobaih (2023) indicated that food waste in Saudi Arabia holds an economic, social and environmental burden. Alnasser and Musallat (2022) revealed that consuming plant-based diets is more environmentally friendly and enhances the sustainability of the food system compared to meat consumption. Many authors, including Alnasser and Musallat (2022), emphasize the importance of reducing food waste and loss to enhance food

Table 5 Future production forecast for selected food items (in thousand mt)

Food item	2021	2030	% of change
Wheat production[a]	612.6	830.6	+ 35.6
Barley production	383.3	515.8	+ 34.5
Millet production	12.2	– 22.7	
Onion	298.0	142.4	– 50.0
Potato production	578.1	606.1	4.8
Dates	1565.8	1421.9	– 9.2
Citrus	116.8	144.6	23.8
Hen eggs	348.2	331.8	– 4.7
Sheep meat	90.6	115.1	27.1
Camel meat	108.3	89.1	– 17.7
Chicken meat	910.0	846.6	– 7.0
Milk (camel, cattle and goats)	2831.3	2514.0	– 11.2

Source Author compilation based on data from FAOstat.org (2021)
[a] Use an exponential function for prediction

sustainability while Sobaih (2023) reflect on food waste reducction as high strategic priority. On the other hand, increasing consumption of plant-based diets and fish and seafood from sustainable sources will also play a vital role in food sustainability and security.

5 Conclusion and Prospects

Saudi Arabia is determined to be food secure, despite relying heavily on food imports (80%) made possible by returns from oil exports. This determination is driven by factors such as global climate change, resource exploitation and depletion, food shocks and crises, and a growing population, all of which highlight the importance of sustainable food production. In light of this, the Saudi Vision 2030 recognizes the importance of concurrently promoting food security and resource sustainability. Despite challenges such as an unfavorable climate and limited natural resources, Saudi Arabia has made efforts to improve food security and production within the country. The production patterns have changed over the years, adapting to changes in population preferences and modernization. Agricultural production, which is generally irrigated, has historically relied heavily on wheat production, causing strain on underground water and necessitating the exploration of alternative options. Vegetable and fruit production, on the other hand, has expanded mainly through the use of greenhouses. Animal products such as eggs, milk, poultry, and red meat have seen considerable growth. The Saudi government has taken steps to ensure an adequate and varied food supply over time to meet health and nutrition requirements. The high demand for mead among Saudis is due to social and cultural factors, but this increased food supply has led to a high amount of food waste and loss. In fact, Saudi Arabia ranks among the highest countries for food waste and loss, indicating the need for action by the community and government to address this issue. Some solutions to enhance food sustainability in Saudi Arabia include improving resource utilization efficiency through the adoption of improved production technologies like greenhouses, and raising awareness among the populace about increasing consumption of plant-based diets and environmentally friendly products like fish and seafood as alternatives to animal products. Additionally, reducing household and retail waste can significantly improve food sustainability.

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Chapter 6
Role of Livestock on Food Security in Saudi Arabia

Abdallah Tageldein Mansour and Adam E. Ahmed

Abstract All nations around the world strive to achieve food security by relying on their resources, protecting their communities, and preserving social cohesion. The livestock sector plays a crucial role in providing the necessary animal protein in adequate quantity, contributing to 18% of global food energy consumption and 34% of global protein consumption to ensure food security. Livestock-based products provide a unique source of high-quality proteins (18–28%), bioavailable essential vitamins (vitamin B12), and minerals (iron and zinc). In addition to the direct contribution of livestock to food security, it can also indirectly contribute by providing revenue from the sale of livestock and animal products, contributing to job creation, and rural development. Saudi Arabia, which is one of the main red meat consumers in the world, has seen a substantial increase in livestock production in the past few decades due to improved genetics, better feeding practices, and increased investment in the livestock sector. It is home to some of the largest livestock producers in the Middle East, including Almarai, NADEC, and SALIC. Saudi livestock production is expected to reach 4,477,200 heads by 2026 with a high annual growth rate (9.2% per year). However, there is still a significant gap in self-sufficiency of red meat in Saudi Arabia which is filled with imported live animals and fresh or processed meat. The sector faces several challenges, such as limited availability of feed and water resources and disease outbreaks. The Saudi government has been working

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to address these challenges by increasing investment in water conservation technologies, researching alternative feed sources, and implementing disease control measures.

Keywords Animal protein · Food security · Food security pillars · Livestock · Saudi Arabia

1 Introduction

The concepts of food and nutrition security exists when all people at all times have physical, social and economic access to food, which is consumed in sufficient quantity and quality to meet their dietary needs and food preferences, and is supported by an environment of adequate sanitation, health services and care, allowing for a healthy and active life. There is a significant correlation between the concepts of food security and nutrition security, with some fundamental differences between them. The concept of food security refers to the availability of food in appropriate quantities for all members of society at all times and depends on the availability of food at the local and global levels, as well as the individual and family's ability to access and use food properly. Nutrition security is a nutritional condition requiring adequate access to healthy foods and appropriate nutrition, as well as access to appropriate nutrition, care, and hygiene practices, as well as access to proper health, water, and sanitation services.

The report from the International Food Policy Research Institute (IPFRI) in 2018 highlighted that the global food system is facing a number of challenges. One of these is the increasing number of people who suffer from chronic hunger, which affects 10.2% of the world's population of 8 billion (IPFRI 2018). Additionally, undernourishment persists, with a quarter of the population lacking essential nutrients, and 155 million children suffering from stunting. Food systems also contribute significantly to greenhouse gas emissions and the depletion of scarce resources like water and arable land. In fact, the agricultural sector consumes over two-thirds (70%) of water consumption and one-third (35%) of the land area, while the animal sector accounts for around one-sixth (15%) of greenhouse gas emissions. Looking ahead, challenges such as population growth, rising concerns about food safety and quality, and increasing inequality pose significant obstacles for the future of global food systems. Livestock can play a key role in addressing these challenges, since it is a major source of income, productive assets, and job opportunities for small farmers and livestock breeders. Livestock can also help to reduce malnutrition among children in developing countries by providing important animal-based foods. However, ensuring the sustainability of this contribution to food security requires the development and implementation of effective policies for the livestock sector. For example, policies that focus on reducing greenhouse gas emissions and improving the efficiency of animal production through good nutrition practices, manure management, and recycling.

2 Livestock and Food Security

Livestock can play a significant role in achieving the Sustainable Development Goals (SDGs) if used and managed properly. For example, livestock provides a source of income, which is in line with the first goal of sustainable development, poverty eradication (SDG1). Moreover, livestock is responsible for providing essential animal products such as meat, milk, and their by-products, which contributes to food and nutritional security and helps to achieve the second and third goals of sustainable development, which are the complete eradication of hunger (SDG2) and ensuring a healthy life and well-being (SDG3). Livestock also contributes to achieving gender equality and empowering women (SDG5). Women in developing countries actively participate in caring for different types of livestock, which enables them to share responsibility within the household. Additionally, livestock promotes sustainable production and consumption practices (Goal 12) and combats climate change (Goal 13) (FAO 2016a).

Recently, achieving food security has become one of the important processes that all countries in the world strive for. It involves relying on their capabilities to secure their communities and maintain social cohesion (Thompson et al. 2010). Food security has a significant impact on health and community security, so countries worldwide seek to fulfill their food and energy needs to protect their societies from shortages, ultimately achieving food security. Achieving food security depends on three main factors—agriculture, industry, and energy (Arizpe et al. 2011).

Livestock production is crucial for meeting society's nutritional, educational, and economic needs, and for promoting sustainability on a global scale. Livestock plays a variety of roles, such as being a source of wealth, food, social status, traction, and household resilience insurance. Livestock waste is also used for various purposes, including fertilizing crops, building materials, and fuel for cooking and heating. According to recent statistics, approximately 18.7% of the world's population is employed in the livestock industry, and this sector provides livelihoods for about 9.4% of the global workforce. In terms of nutrition, livestock accounts for approximately a quarter of protein and 18% of calories consumed across the world. Livestock also plays a crucial role in empowering female household heads and smallholder producers. The reuse of feed can help in reducing food loss and waste (McKune 2023).

In the context of food and nutritional status, livestock industry is extremely important in providing animal protein, such as red meat, milk, and their byproducts, in sufficient quantities. Additionally, sources of poultry and fish also play a role in sustaining food security around the world, both directly and indirectly (Michalk et al. 2019). It is estimated that foods derived from livestock make up 18% of the global food energy consumption and 34% of global protein consumption (FAO 2016b). Products based on livestock are a unique source of high-quality protein (18–28%), bioavailable essential vitamins (such as vitamin B12 and other B complex vitamins), and essential minerals (such as iron and zinc). A 100 g serving of cooked beef contains around 22–30 g of protein, which is equivalent to 44% of the daily recommended value for adults. It also contains around 2.1 mg of iron, which makes up 12% of the daily recommended value (USDA 2021). Furthermore, livestock products have a considerable amount of fat, which varies in percentage and fatty acid profile depending on the species, feeding system, and cut of meat (Pereira and Vicente 2013).

Additionally, milk and its derivative products are excellent sources of various macro- and micronutrients, including protein, fat, lactose, calcium, vitamin D, and vitamin B12, as well as other vital nutrients. A single cup of whole milk (250 ml) contains roughly 276 mg of calcium, equating to roughly 21% of the daily value (DV) for adults. It also contains approximately 2.9 μg of vitamin B12, equating to approximately 120% of the DV for adults (Chalupa-Krebzdak et al. 2018). In addition to being a direct source of animal protein for food security, livestock can also indirectly contribute by generating revenue from the sale of livestock and animal products, which can then be used to purchase food, particularly during times of food scarcity (Sekaran et al. 2021). In addition, an increase in livestock production may lead to lower prices for livestock products, making them more accessible to low-income individuals, particularly those residing in urban areas (Herrero et al. 2013). Finally, livestock manure can be used as organic fertilizer to enhance farming productivity and increase the supply of cereal crops (Xia et al. 2017).

On the other side, livestock may impact food security through its effect on human health via diseases or contaminations for food products through feces or contact with infected animals. Additionally, livestock can have a significant impact on food and nutritional security through the following effects. The profits earned by farmers through the sale of animals can finance inputs for agricultural operations. Small farmers may also purchase livestock at the end of the harvest season, which provides insurance during critical times of need for money and food. Therefore, livestock plays a vital role in agricultural production and is essential for household food security. In some countries, livestock is used in agricultural operations and contributes to the movement of farmers from rural to farm areas. However, livestock can also negatively affect food security through the transmission of animal diseases to humans, the contamination of agricultural products with diseased animal waste, and the interference of livestock keepers feeding their animals from farmers' crops. These factors can significantly decrease food production, ultimately affecting food security, quality, and safety.

In Saudi Arabia, various types of meat, such as camel, cow (including dairy cows), sheep, goat, and poultry as well as eggs are produced through in-house and open grazing farming. The type and quality of these livestock products are dependent on the regional location, climatic conditions, as well as the applied farming techniques (Chowdhury et al. 2017). Over the past three years, the total livestock production in Saudi Arabia per 1000 animals has significantly increased. According to AOAD's report in 2021, there was a 5.18% increase in 2019 compared to 2018, and a 13.08% increase in 2020 compared to 2019.

Food security, as defined by the FAO in 1996, comprises four pillars: food availability, accessibility, utilization, and stability. Table 1 displays how livestock can impact the pillars of food security by providing animal-derived food, increasing food crop productivity, generating income, improving resilience to climate change, and benefiting women. Various methods that demonstrate these effects are summarized in Table 1. Positive signs (+) indicate a positive effect, while negative signs (−) indicate a negative impact.

3 Livestock Production in Saudi Arabia

In recent decades, the Arab region has experienced a significant growth in livestock production. There are multiple reasons for this increase, such as enhanced genetics, improved feeding methods, and more investment in the livestock industry (Abdel Monem and Radojevic 2020). The surge in livestock production has positively affected the economies of numerous Arab nations by providing job opportunities, ensuring food security, and promoting rural development (Jaber et al. 2016).

Livestock production in the Arab region is varied and includes a variety of animals, such as camels, sheep, goats, and cows. According to the FAO, the region is responsible for approximately 11% of the world's livestock population (refer to Fig. 1). Some of the world's largest livestock producers, including Sudan, Somalia, Egypt, and Saudi Arabia, are located in the Arab region (FAO 2021).

The livestock industry in the Arab region has experienced a steady growth for the past few decades. From 2000 to 2016, the number of animals in the region increased by 48%, from 311 to 461 million. The reasons for this growth can be attributed to various factors such as the rising demand for animal protein, better breeding methods, and improved feeding practices. Additionally, the demand for livestock products increased in the Arab region due to high population growth coupled with varying degrees of urbanization and wealth (Jaber et al. 2016).

In 2020, Saudi Arabia ranked near the bottom of the top ten Arab countries for livestock production (Fig. 2). However, there has been a significant increase in total production over the past five years, with a 140% rise from 2015 to 2020 according to AOAD (2021) (Fig. 3). Furthermore, it is expected that Saudi Arabia's livestock production will continue to grow at a high annual rate of 9.2% and reach 4,477,200 heads by 2026, thanks to various leading livestock-producing companies (ReportLinker 2023). Despite the growth in livestock production in Saudi Arabia, the sector still faces several challenges. One major challenge is the limited availability of feed and water resources. Saudi Arabia's location in an arid region leads to water scarcity, which limits the availability of pastureland and feed resources for livestock. This scarcity also affects the cost of livestock production (van de Steeg and Tibbo 2012).

According to AOAD (2021), there has been a notable increase in cattle production in Saudi Arabia. Goats and sheep populations have also increased, as revealed by statistics in Table 2. Conversely, the populations of camels, horses, mules, and donkeys have remained relatively stable over the last few years. The rise in cattle and goats indicates a growing demand for meat and dairy products. However, the stable populations of camels, horses, and mules suggest that these animals are more culturally and traditionally significant rather than commercially viable.

Table 1 Livestock's contribution to food security pillars

Livestock contribution	Causal/determinants	Food security pillars			
		Availability	Accessibility	Utilization	Stability
Foods of animal origin	The consumption of animal-derived foods (+)	√	√	√	√
	Improve crop yield by utilizing manure (+)	√			
	Improve nutrition by providing high-quality food (+)	√		√	
	Transmission of diseases from animals to humans (−)	√	√	√	√
	The preservation and processing of animal products (+)	√	√	√	√
Increase food crops productivity	Livestock as an energy source (+)	√	√	√	√
	Assists in weed management (+)	√	√	√	√
	Using animal manure as a fertilizer (+)	√	√	√	√
	Financing agricultural production through selling animals (+)	√	√	√	√
Income sources	Jobs and labor related to the livestock industry (+)		√	√	√
	Selling animals, animal products, and by-products (+)	√	√		
	Animal rearing labor—physical activities (±)			√	
	Processing of animal products (+)	√	√	√	√
Resilience to climate change	Increase crop production (manure) (+)	√			√

(continued)

Table 1 (continued)

Livestock contribution	Causal/determinants	Food security pillars			
		Availability	Accessibility	Utilization	Stability
	GHGs emission (−)	√	√	√	
	Water consumption (−)	√	√	√	
	Livestock land use versus other uses (+)	√	√	√	√
Women empowerment	Creating employment opportunities for women in the livestock industry (+)	√	√	√	√
	Animal raring (±)				
	Processing local animal products (+)	√		√	√

Source Author compilation

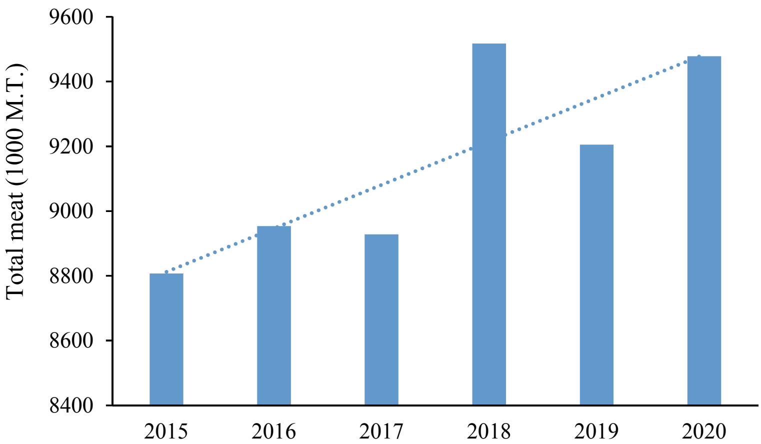

Fig. 1 Total meat production in the Arab region from 2015 to 2020 (AOAD 2021)

Regarding the production and consumption of red meat in Saudi Arabia, the growing demand for meat has resulted in significant investment in the livestock sector. Saudi Arabia is among the largest meat-consuming nations globally, with an average consumption of approximately 64 kg of meat per person per year. The country's meat consumption is expected to continue to rise due to urbanization, population growth, and increasing income levels (Abdelradi et al. 2021). As a result, the livestock industry in Saudi Arabia is expanding, and the government is investing heavily in increasing domestic meat production. According to the Ministry of Environment,

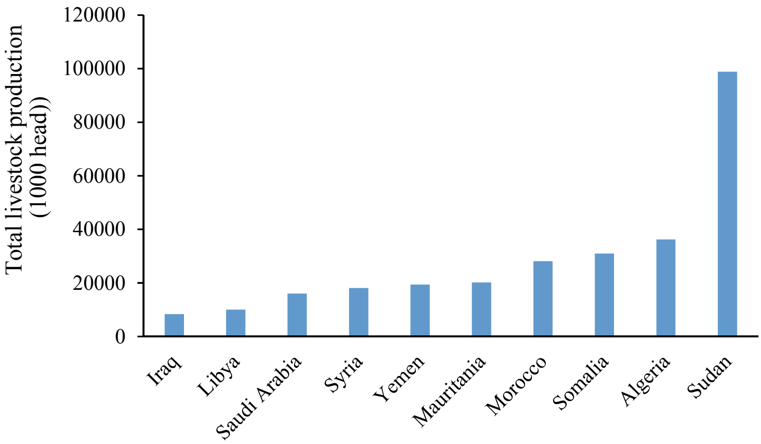

Fig. 2 Total livestock production (1000 head) in the top ten Arabian countries in 2020 (AOAD 2021)

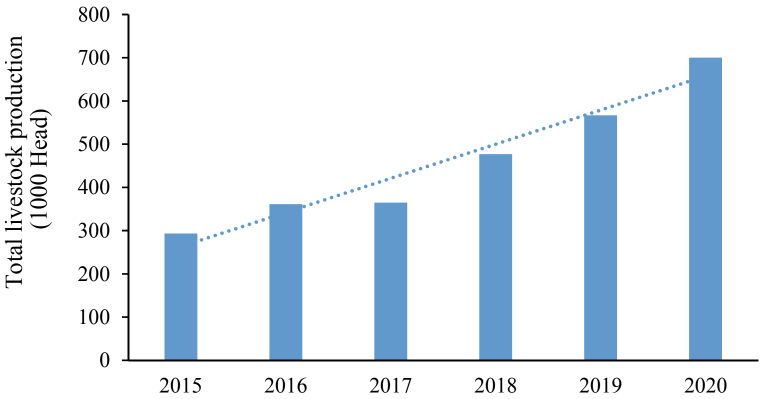

Fig. 3 Total livestock production in Saudi Arabia from 2015 to 2020. *Source* AOAD (2021)

Table 2 The production of various species of livestock in Saudi Arabia between 2015 and 2020

Livestock heads (1000 head)	2015	2016	2017	2018	2019	2020
Cattle	293	361	365	477	567	700
Sheep	11,613	11,008	9327	9396	9420	9447
Goats	3150	2597	3670	3608	3711	6100
Camels	476	481	486	488	493	500
Horses	29	34	28	28	32	32
Mules and donkey	99	98.8	99.0	98.9	98.8	98.9
Total livestock	15,660	14,580	13,975	14,096	14,322	16,878

Source Compiled by the author based on data from AOAD (2021)

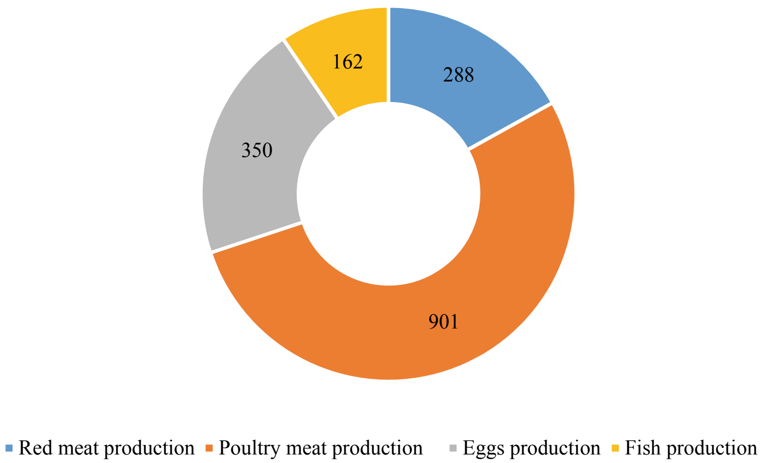

Fig. 4 Main type of produced protein (1000 M.T.) in Saudi Arabia in 2020. *Source* AOAD (2021)

Water, and Agriculture, the country produced 1.5 million metric tons of meat in 2020, with poultry accounting for the majority of production (Fig. 4) (Ministry of Environment, Water, and Agriculture 2020).

The production of meat is an essential aspect of Saudi Arabia's plan to improve its food security and diminish its reliance on imported goods (Fig. 5). The government has launched various initiatives to enhance local meat production, such as providing subsidies to livestock producers, developing specialized livestock farms, and investing in research and development.

4 Livestock Farming Systems in KSA

In Saudi Arabia, there are several leading livestock companies, both governmental and private mega projects, that work to sustain domestic meat production. Recent years have seen heavy government investment in the livestock sector to increase domestic production and reduce the country's dependence on imports (Ministry of Environment, Water and Agriculture 2020). Significant climatic variability between the northern and southern regions of Saudi Arabia affects the efficiency of livestock production. To aid in the understanding of the effects of environmental conditions on livestock production, the term "virtual water content" (VWC) is used to represent the amount of water used to produce one ton of product (Chowdhury et al. 2017). In Saudi Arabia, the VWC of livestock farms to produce one ton of beef was found to be 11,359 m^3, which was 30% higher than in Germany. Differences in VWC were linked to production efficiency, including factors such as climatic variability, farming practices, feed consumption, and genetic merit of animals (Chapagain and Hoekstra 2003).

Fig. 5 Domestic meat production in Kingdom of Saudi Arabia. *Source* By the first author

Livestock farming systems in Saudi Arabia vary based on factors such as the region, type of animal, and purpose of production. These systems are customized to fit the local conditions, availability of resources, and market demand (Al-Shayaa et al. 2012; Ministry of Environment, Water, and Agriculture 2020). Figure 6 provides some examples of common livestock farming systems in Saudi Arabia.

1. Intensive systems are typically used for poultry and dairy farming where animals are confined and fed high-quality, specially formulated diets. These systems generally keep animals indoors in climate-controlled environments to optimize production.
2. Semi-intensive systems are commonly used for sheep and goat farming. In these systems, animals graze on natural pastures but may also receive supplementary feeding in the form of grains or concentrate. Animals are housed at night and during the hottest part of the day to avoid heat stress.
3. Extensive systems are commonly used for camel, sheep, and goat farming. Animals are grazed on natural pastures with minimal or no supplementary feeding. Animals in these systems are allowed to roam freely and are not confined to pens or stables.
4. Mixed systems are a combination of intensive, semi-intensive, and extensive systems and are common on large commercial farms. These systems allow for a diversity of production depending on the availability of resources.

There are numerous companies that are engaged in meat production in Saudi Arabia. However, the foremost and most prominent company in this field is Almarai Company (Ministry of Environment, Water and Agriculture 2020). Almarai is a huge

Fig. 6 Different farm animal species in Saudi Arabia. *Source* By the first author

conglomerate whose primary activities include dairy and poultry production, while also having a sizeable presence in meat production. The Company is headquartered in Riyadh and operates numerous meat processing farms throughout the country. Almarai has lately been expanding its meat production operations. It is part of its strategy to diversify its product portfolio and obtain a greater share of the domestic market. In addition to Almarai, other major players in the meat production sector in Saudi Arabia include the National Agricultural Development Company (NADEC). While primarily known for its dairy and juice products, the company also has a presence in meat production in Saudi Arabia. Another noteworthy company is the Saudi Agricultural and Livestock Investment Company (SALIC), which was established by Royal Decree No. M/22 dated 4/14/2009 AD as a Saudi joint-stock company owned by the Public Investment Fund. SALIC aims to be a leading global food security company focused on sustainable agribusiness investment, starting with their investment in meat production with many global companies in the field of agriculture and livestock in different countries. Additionally, there are tens of companies that work in livestock production in Saudi Arabia.

There are several leading livestock companies in Saudi Arabia, including both governmental and private mega projects, that aim to sustain domestic meat production. Recently, the government has heavily invested in the livestock sector to increase domestic production and decrease reliance on imports (Ministry of Environment, Water and Agriculture 2020). Due to significant climatic variability between the northern and southern regions of Saudi Arabia, livestock production efficiency is affected. To better understand the environmental effects on livestock production, the term virtual water content (VWC) is used to represent the amount of water required to produce one ton of product (Chowdhury et al. 2017). In Saudi Arabia, the VWC for producing one ton of beef was 11,359 m^3, which is 30% higher than in Germany. Differences in VWC are related to production efficiency, including climatic variability, farming practices, feed consumption, and the genetic merit of animals (Chapagain and Hoekstra 2003).

4.1 Export and Import of Livestock Products

Cattle production has had a significant impact on the economies of many Arab countries. Livestock farming is heavily relied upon in many rural areas as a source of revenue which creates jobs and promotes rural development. However, livestock production faces additional challenges due to arbitrary national policies that disproportionately affect small farmers and degrade national resources. Saudi Arabia depends on global trade to fill its gap in livestock and animal feed supplies, with different trading strengths depending on affluence and the presence of free trade agreements (Jaber et al. 2016). In 2020, Saudi Arabia exported a total quantity of 68.91 thousand metric tons of all types of meat with a combined value of 198.31 million USD. These exported meats were mainly prepared or preserved meats, offal, followed by fresh meats (Table 3). In contrast, the import situation of live animals, as well as different types of meat products in Saudi Arabia, revealed that the main imported live animal was live sheep with a total quantity of 3572.43 thousand mt and a total value of 420.36 million USD, followed by live cattle at 202.32 thousand mt and a total value of 78.25 million USD (AOAD 2021).

In the meantime, the first-ranked imported meat of bovine animals (fresh, chilled, or frozen) amounted to 109.73 thousand mt, with a total value of 534.21 million USD. This was followed by meat of sheep and goat (fresh, chilled, or frozen) at 20.33 thousand mt, with a total value of 114.1 million USD. The total combined import of live animals and meat products was 4309.67 thousand mt, with a total value of 1220.32 million USD (refer to Table 4).

According to statistics provided by AOAD in 2021, it seems that Saudi Arabia imports more live animals and meat than it exports, with a total of 4309.67 thousand mt of live animals and meat imported, valued at 1220.32 million USD. In the same year, Saudi Arabia exported 68.91 thousand mt of meat, valued at 198.31 million USD, making it a relatively small net exporter of meat (Fig. 7). The large difference between imported and exported quantities indicates that, overall, Saudi Arabia

Table 3 Exported livestock products in Saudi Arabia for the year 2020

Items	Export during 2020	
	Quantity (1000 mt)	Value (million USD)
Total of red meat (fresh, preserved and meat preparations) exports	3.72	11.60
Other edible offal meat (fresh, chilled, or frozen) exports	0.13	0.36
Total meat (dried, salted, canned, and meat preparations) exports	0.14	0.11
Total of red and poultry meat exports	34.49	130.42
Sausages and similar products exports	1.72	2.97
Prepared or preserved meat, offal or blood exports	28.71	52.86
Total exported animal protein	68.91	198.31

Source AOAD (2021)

Table 4 Imported livestock products in Saudi Arabia for the year 2020

Items	Import during 2020	
	Value (million USD)	Quantity (1000 mt)
Live cattle	78.25	202.32
Live sheep	420.36	3572.43
Live goats	15.5	279.79
Live camels	36.1	112.6
Total live animal	550.21	4167.14
Meat of bovine animals (fresh, chilled, or frozen) imports	534.21	109.73
Meat of sheep and goat (fresh, chilled, or frozen) imports	114.1	20.33
Camel meat imports	0.14	0.03
Edible offal of bovine animals, sheep, and goat imports	21.66	12.44
Total red meat (fresh, preserved and meat preparations) imports	670.11	142.53
Total imported live animal and meat	1220.32	4309.67

Source AOAD (2021)

imports significantly more meat than it exports. This means that there is a high demand for meat in Saudi Arabia, and this demand is mostly met through imports.

Local livestock production in the area is heavily reliant on rainfed mixed and pastoral systems, which makes it vulnerable to the negative impacts of climate change and water scarcity. Intensive farming methods, where they are used, heavily rely on

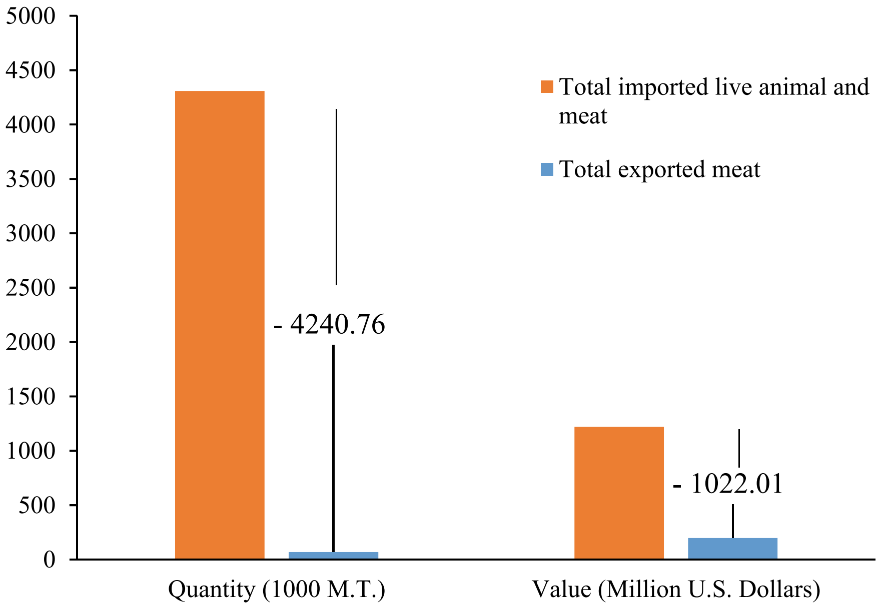

Fig. 7 The difference in meat imports and exports in Saudi Arabia for the year 2020. *Source* AOAD (2021)

imported feed which requires substantial amounts of water (Jaber et al. 2016). The Saudi Arabian government has invested in research and development to improve feed and water management strategies to address the challenges associated with livestock production. One promising approach is the use of hydroponics to cultivate cattle feed in arid regions. Hydroponics involves growing plants in nutrient-rich water instead of soil, which could greatly increase the supply of feed for cattle in the region (Girma and Gebremariam 2018).

4.2 Self-sufficiency of Livestock Products in KSA

The Food and Agriculture Organization (FAO) defines 'food self-sufficiency' as the extent to which a country is capable of fulfilling its own food requirements through domestic production (FAO 1999). Recently, the General Authority for Statistics (GASTAT) has issued a report on agricultural statistics for 2021, which includes the self-sufficiency ratio (SSR) for crucial agricultural products. Of the livestock products produced in the Kingdom, dairy had the highest SSR at 121%, accompanied by table eggs with an SSR of 112% and fish with an SSR of 40% (Table 5). Dates had the highest SSR of all agricultural products, with 118% and a local production of 1.57 million tons in 2021. In contrast, tomatoes and onions only had SSRs of 77%

Table 5 Saudi Arabia self-sufficiency ratio for animal products in 2021

Product	Self-sufficiency ratio
Dairy products	121
Table eggs	112
Poultry meat	66
Red meat	43
Fish	40

Source Compiled by the author based on the data from General Authority for Statistics (2021)

and 52%, respectively. The Kingdom's overall agricultural imports for 2021 totaled 20.04 million mt, with grains accounting for 42.5%. Meanwhile, agricultural exports came to about 2.65 million mt, with dairy goods, eggs, and natural honey making up 23.5% of the total.

5 Future Prospects of Livestock in Saudi Arabia

Approximately 80% of Saudi Arabia's food is imported, which makes it the largest individual food importer in the Middle East. The country expects to consume an estimated 16 million mt of food annually, with an anticipated increase of 4.6% per year. Saudi Arabia's most ambitious agricultural goal is to achieve self-sufficiency and transition from a food importer to an exporter, focusing on essential commodities such as wheat, dates, dairy products, meats, and vegetables, and targeting key global markets. This objective aligns with the country's priority for food security. Food security is a critical issue for every economy, including Saudi Arabia, considering various factors such as water scarcity, land usage, climate change, and human capital. It is crucial to develop innovative food production efforts that can address the predicted significant population growth in the next decade. As the population expands, there is also a shift in nutritional preferences, particularly among the younger generation, who tend to favor higher processed food, meat, and dairy consumption, leading to a change in menu trends.

6 Conclusion and Prospects

In recent years, there has been significant growth in the livestock sector throughout the Arab region. This growth has played a crucial role in creating job opportunities, promoting rural development, and strengthening food security. In Saudi Arabia, livestock holds great importance in achieving food security as it is linked to all aspects of food security. However, the challenging climate, limited agricultural land suitable for crop cultivation, and scarcity of water make livestock a significant source of protein for the population. The Saudi government has dedicated considerable efforts to support the livestock sector through various initiatives, strategies, and programs aimed at increasing production and improving the quality of animal products. However, there are still challenges to be addressed to ensure the sustainable growth of the livestock industry in Saudi Arabia. These challenges include enhancing production efficiency, managing limited water resources, promoting sustainable grazing practices, tackling insufficient feed and water resources, and dealing with the consequences of climate change. Furthermore, it is necessary to increase investments in research and development to address issues related to animal health and nutrition. Looking ahead, the livestock industry in Saudi Arabia holds great potential. The country has the opportunity to become a major player in the global livestock market, as long as the government continues to invest in the industry and overcome the challenges it faces. This can be achieved by improving feed and water management techniques and incorporating the latest technologies to enhance the productivity and sustainability of livestock farming. By doing so, Saudi Arabia can ensure long-term food security for its population and make a meaningful contribution to the global food supply.

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Chapter 7
The Role of Poultry Production on Food Security in Saudi Arabia

Huthail Najib and Ahmed Magzoub Khalid

Abstract Poultry farm projects in Saudi Arabia have the potential to bring numerous advantages to entrepreneurs and households and local areas. The government of Saudi Arabia has placed improving the self-sufficiency ratio of poultry products as one of the priorities in both agriculture and food security strategies to enhance and achieve food security. This chapter gives an overview of the poultry sector, focusing on the significance of poultry companies and poultry products in Saudi Arabia's food security, as well as the efforts and support provided by government institutions to improve the poultry industry and address issues of poultry loss and waste.

Keywords Broilers · Egg layers · Food security · Healthy food · Poultry industry · Saudi Arabia

1 Introduction

This section will provide a brief history of the poultry industry in Saudi Arabia. The poultry industry began in the Kingdom of Saudi Arabia in 1976, initially with a limited production capacity in the Taif region. However, in 1982, the industry experienced a significant increase in production. This was made possible by the implementation of three projects in Riyadh, Qassim, and Jeddah, each with a production capacity of 30 thousand tons. In addition, the Al-Akhawain project, with a capacity of 8 thousand tons, was also established in Al-Kharj in 1994. As a result of continuous

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expansion, the production capacity reached 615.9 thousand tons in 2017 (Al-Duwais and Ghanem 2019) Saudi Arabia possesses a substantial capacity for producing poultry meat domestically. However, it falls short of meeting the domestic demand. According to the United States Department of Agriculture (USDA), the percentage surpasses 60%. In 2020, the production volume reached 900,000 metric tons and 910 thousand in 2021. As a result of these factors, the Government of Saudi Arabia is concentrating on implementing strategic measures to enhance local production and subsequently stimulate market growth (Mordor Intelligence 2023). The size of the Saudi Arabia Poultry Market is anticipated to increase from USD 17,328.07 million in 2023 to USD 21,193.97 million by 2028, with a compound annual growth rate (CAGR) of 4.11% during the forecast period (2023–2028) (Mordor Intelligence 2023). Despite its growth, the poultry industry in the Kingdom of Saudi Arabia faces various challenges according to local producers, including the possibility of unfair competition in the form of dumping from other countries, a rise in imports, high costs of storage and production, a lack of adequate storage facilities, difficulties in communication between producers and wholesalers, insufficient and inaccurate marketing information, and the absence of specialized marketing companies for broiler chickens (Al-Nashwan et al. 2008).

The poultry sector is considered one of the vital and important sectors in the Saudi economy. Poultry provides approximately 45% of the population's animal protein needs in the Kingdom (Al-Rajhi 2008). The poultry industry in Saudi Arabia is one of the largest food industries in the Kingdom, where millions of poultry are raised for the production of eggs and meat. Poultry, alongside fish, meat, and eggs, is one of the most important food sources rich in protein and other nutrients (Yaseen 2021). It represents an important resource for meeting the nutritional needs of Saudi society. The pharmaceutical industry related to poultry production also plays a significant role in providing job opportunities and improving the income level for many families in the Kingdom, employing trained and skilled workers. The Saudi government aims to support and develop the poultry industry to reach self-sufficiency in food production, achieve food security for citizens, and reduce reliance on agricultural and food imports. They also attempt to enhance the quality of pharmaceutical products, as well as develop production and marketing techniques to improve efficiency and competitiveness in local and global markets. The poultry industry in Saudi Arabia contributes to achieving food security, job creation, and income improvement for many families in the Kingdom. It is experiencing continuous growth due to government support and development initiatives. The industry offers diverse products, including various types of poultry for meat and eggs. Frozen, canned, and fresh poultry are available in the Saudi market. Saudi Arabia is planning to invest SAR 17 billion ($5 billion) in order to increase poultry production. The goal is to achieve a self-sufficiency rate of 80% in poultry meat by 2025, according to the Saudi Press Agency. The Ministry of Environment, Water and Agriculture, led by Abdulrahman Al-Fadley, aims to produce 1.3 million tons of broiler chickens annually. This initiative seeks to guarantee the country's food security, promote domestic products, and generate employment opportunities (Arab News 2022).

The poultry products sector offers numerous benefits for individuals, families, institutions, companies, and the nation as a whole. Poultry products have multiple advantages that impact all aspects of food security at various levels. These benefits include generating diverse sources of income, providing a wide variety of protein-rich and nutritious food, contributing to food security, supporting rural development through poultry production projects, improving farmers' livelihoods (especially for those who are economically disadvantaged), and diversifying agricultural products. Moreover, it plays a role in agriculture, food security, and health. Additionally, it serves as a source of income for the government and promotes economic integration with trading nations through intra-trade. Furthermore, production projects aid in achieving self-sufficiency in poultry meat and eggs, ultimately reducing the need for importing such products (Alraedah 2023).

Poultry products are an essential food commodity for achieving food security in Saudi Arabia. According to Alamri and Al-Duwais (2019), they have a positive impact on food security, the food gap, strategic stock, and the self-sufficiency ratio. Verdruye's analysis in 1967 showed that intensive poultry production was almost non-existent. Local production only met less than 50% of the nation's egg needs, and small flocks were the primary source. Over 24 million eggs were imported in 1964 alone. Imports also supplied half of the country's broiler meat needs, totaling 800–900 tons per year, while the remaining meat was domestically produced using imported chicks. Suggestions to the government included implementing a national strategy to grow the poultry industry, establishing a poultry extension service, and creating a poultry unit under the Ministry of Agriculture.

Several studies have been conducted to conserve the native or local chicken flocks that originated in Saudi Arabia, called Baladi, and are adapted to their environment. These birds are characterized by their small size, different plumage colors, and different comb shapes (Al-Yousef 2007). They have a low production rate and small egg sizes, which are inherited traits that make them well-suited to the harsh environment. Baladi chickens are valuable genetic materials that need to be conserved and improved. Some research has been carried out to study the biological characteristics of these birds. Alsobayel (1986) compared two housing systems and their effect on the egg quality characteristics of local chickens reared under different systems. Attia et al. (1991) studied the effect of rearing system and age of the chicken on egg weight. Alsobayel (1992) reported the effect of dietary protein levels and age on fertility and hatchability. Several parameters were studied by Alsobayel et al. (1990) including the effect of storage, egg weight, and moisture loss on hatchability parameters of Baladi chicken eggs. Alsobayel and Atteia (1991) provided evidence of the influence of protein rearing regimens and age on egg quality characteristics.

The production of poultry in the Kingdom of Saudi Arabia dates back to the 1960s. Sheikh Abdul Rahman bin Abdul Qadir Fakih initiated the first commercial poultry project in the Kingdom in 1963. Currently, the Fakih project is one of the biggest customers of the international company, in the Middle East and North Africa.

Saudi Arabia has been very successful in poultry production, including a significant increase in the supply of both poultry meat and eggs. The Saudi Arabian former Ministry of Agriculture reported that the country's domestic poultry production exceeded 493 million hens in 2009, with an egg production of 3473 million, as well as approximately 476,348 tons of chicken meat in specialized projects. Additionally, there were around 522 million meat chicks and 21.4 million egg chicks in the same year. This has resulted in Saudi Arabia being among the highest consumers of poultry in the world, with an annual consumption of 41.6 kg per capita of chicken, compared to the global average of only 12.5 kg (MOA 2009; Global Poultry Trends 2010).

Apart from the approximately 1500 mt of quail meat produced by Astra Farms in Tabuk, almost all poultry meat produced in Saudi Arabia is chicken meat. After consulting with the leading chicken meat producers in the country, the Saudi predictions for chicken meat production in 2019 and 2020 have been updated. According to these firms, around 800,000 mt of chicken meat were produced in 2019, which is an increase of 11% over the USDA's estimate of 720,000 mt. The overall output of chicken meat in Saudi Arabia is expected to exceed 930,000 mt in 2020, which is more than 27% higher than the USDA's official projection of 730,000 mt. The increase in chicken meat production can be attributed to the continued growth of the four major producers, namely Watania, Fakieh, Alyoum (Almarai), and Tanmiah poultry farms. Medium-sized chicken producers like Intaj and Aseer CO-OP, as well as smaller farms like Radwa and Golden Chicken, have also been contributing to filling the gap in meat production. Furthermore, expansion projects at existing farms and the establishment of new farms are expected to raise chicken meat output to 950,000 mt by the end of 2021, facilitating sustainable growth over the next few years (Mousa 2020).

In 2016, Selvanathan and colleagues conducted research on the consumption patterns of meat and fish in Saudi Arabia. The researchers examined data from 1985 to 2010 in order to investigate the demand for beef, chicken, lamb, and fish within an overall framework. Their findings revealed that the consumption rates of beef, chicken, and fish were on the rise, while lamb consumption was decreasing in Saudi Arabia. Additionally, they observed that the average relative price growth rates for beef, chicken, and fish were negative, while that for lamb was positive. Over time, the proportion of expenses allocated towards beef, chicken, and fish has increased, whereas the proportion allocated towards lamb has decreased. The income flexibility analysis showed that beef, lamb, and fish were considered luxuries, whereas chicken was a necessity in Saudi Arabia. Finally, the research revealed that the demand for all meat products and fish were price inelastic.

This chapter focuses on the historical importance of poultry products and farms in improving food security and bridging the gap between poultry product production and consumption. It also highlights the role of poultry in generating diverse income sources and providing nutritious protein. Additionally, it discusses the development and expansion plans of large and small poultry companies, as well as government initiatives to enhance the poultry sector's contribution. Lastly, the chapter addresses the significance of poultry products in ensuring food security and the need to minimize food loss and waste in the poultry industry.

2 Major Poultry Companies in Saudi Arabia

2.1 National Poultry Company (Al-Watania)

The National Poultry Company has become the biggest poultry facility in the Middle East and one of the largest in the poultry industry worldwide. The project is situated in Qassim city, located in the northern region of the Kingdom of Saudi Arabia. With over 5000 employees, Al-Watania Poultry holds a market share of over 40% in the Arab Gulf region, producing more than half a million chickens and one million eggs daily. Al-Watania Poultry takes pride in feeding their poultry a natural and nutritious diet while adhering to Islamic law for slaughter. The company produces around one million chickens and one and a half million eggs on a daily basis while also offering around 50 different chicken-based products. They have achieved recognition as the leading company in the Kingdom of Saudi Arabia for poultry, eggs, and related food products, and their items are present in every household in the country. This success is a result of their relentless pursuit and unwavering commitment to enhancing their products to the highest standards of quality, ensuring the provision of healthy and safe options (Al-Watania 2023).

Al-Watania's vision stated, "To support the food security and national economy through providing the Arab and international markets with the best poultry products that are slaughtered according to Islamic Sharia and by using modern systems that protect the environment and achieve the highest safety standards and sustainable development through employing and developing the human elements that are characterized by efficiency, commitment and effective participation in the constant development" (Al-Watania 2023).

2.2 Fakieh Farms Company for Poultry

Al-Fakieh Poultry Farms, which is owned by Saudi real estate is one of the largest poultry producers in Saudi Arabia. As a part of the Fakieh Group, Al-Fakieh Farms holds a 40% market share. The company's expansion plan is aimed at increasing the production of broilers to 1 million per day. This will be achieved by constructing additional hatcheries, breeding farms, grow-out houses, and a feed mill, which will also create approximately 6000 new jobs. Al-Fakieh Farms was the first Saudi poultry company to establish and operate its own fast-food chain, exclusively serving broiler meat produced on its farms. The first Taza Barbecue Chicken restaurant was opened in 1989. Since then, the chain has grown to have over 100 outlets across the Kingdom, with branches in Kuwait, Jordan, Qatar, Egypt, Oman, Yemen, and the United Arab Emirates.

Fakih Poultry Farms Company is a large integrated project in the Middle East and worldwide. It was established in the early 1960s and continues to thrive today. The domestic production of poultry has been steadily increasing and currently stands at

67%. The company's aim, as a poultry producer, is to become self-sufficient and reach 100% production according to the Saudi government's vision for 2030 (WATTPoultry 2023). The company revealed its plans for expansion as part of its future vision. The goal is to double production in the coming years. These expansions align with the wider plans for poultry production in the Kingdom of Saudi Arabia. As the largest country in the Arab Gulf region in terms of both area and population, Saudi Arabia plays a significant role in poultry farming in the Middle East. The Saudi government is actively seeking innovative solutions to address regional challenges in poultry production and meet the increasing demand. Currently, the Kingdom produces over 1.3 billion birds and 5.4 billion eggs each year. Fakih Poultry Farms Company owns 32 broiler mother farms in Tabuk, Turbah, and Hotat Bani Tamim. These farms consist of 249 barns and have an estimated production capacity of 233 million broiler hatching eggs. Additionally, the company has four hatcheries with a capacity to produce 180 million broiler mother chicks annually. Furthermore, Fakih owns 52 broiler farms in the Najran, Radwan, and Asir regions. These farms consist of 436 barns and have an estimated production capacity of 110 million birds per year. In addition to poultry, the company also produces table eggs. To ensure the quality and safety of their feed, Fakih operates feed laboratories. These labs monitor the feed from the arrival of raw materials at the factory to the final product. The feed is examined to ensure it meets standard specifications before being sent to the farms. The feed is tailored to the specific needs of each farm. Fakih Poultry Farms Company has also established major diagnostic laboratories in Taif Governorate. Equipped with the latest equipment and technologies, these labs are responsible for diagnosing poultry diseases, monitoring the health of the birds during breeding and production, and examining the feed and water consumed by the poultry (Riyadh 2023). Today, it holds a prominent position among the enormous projects in the Middle East, and is one of the most extensive poultry projects globally. It offers consumers healthy and fresh products at an affordable price.

2.3 Almarai Company (Alyoum Chickens)

Almarai, a significant poultry company in Saudi Arabia, acquired the Hadco company in 2009. In 2010, the company changed its name to "Chicken Today" (Alyoum Chickens) and specialized in the production of chickens and eggs. Almarai invested 5 billion riyals in the Hail region of northern Saudi Arabia, where one of the world's largest poultry projects operates. This project has the capacity to produce over 200 million chickens and 300 million eggs annually. The "today's" poultry project aims to increase its production capacity, expand its markets, and venture into new regions. According to Al Mheiri et al. (2020), Al Marai is a company based in Saudi Arabia that specializes in the food industry and has its headquarters in Riyadh. The company's primary focus has been on producing high-quality products that meet improved standards. Almarai aims to provide consumers with nutritious and high-quality food that positively impacts their lives. The company envisions becoming the preferred choice for food and beverage products in the market. Over time, Almarai has improved its financial status and increased its market value, resulting in a significant increase in the number of shareholders, reaching a total of 50,000. Almarai relies heavily on its inventories to fulfill its current obligations. However, the company faces financial risks due to competition in the market, which can only be overcome by increasing its market share. Although Almarai's overall performance is satisfactory, improvements are necessary to effectively compete with its rivals.

2.4 The Arab Company for Poultry Breeders (Ommat)

Ommat specializes in breeding parent stocks. It began the production of flocks in 1990 as the sole distributor of laying chicks in Saudi Arabia, the Gulf States, and Yemen. Its initial project was established on a land area of 500,000 m^2. Ommat, which is the company's commercial name, is among the top companies in the Gulf region, Yemen, Egypt, and Sudan for the production and marketing of poultry products.

3 Impact of Poultry Production on Food Security Pillars in Saudi Arabia

3.1 Importance of Poultry Farms

Food security is an extremely complex topic that includes various fields like agriculture, economics, sociology, culture, engineering, entrepreneurship, environment, politics, human physiology, and more. As stated by the FAO (2009), food security occurs exclusively, "when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". This definition decomposed food security into four pillars, which are food availability, accessibility, utilization, and stability.

According to Mottet and Tempio's (2017) study on global poultry production, the poultry industry is an important contributor to food security and nutrition. It provides humans with energy, protein, and essential micro-nutrients. Poultry has the advantage of having short production cycles and the ability to convert various agri-food by-products and wastes into meat and eggs that can be consumed by humans. It is also the fastest-growing agricultural sub-sector, particularly in developing countries. The demand for meat and eggs worldwide is increasing due to population growth, rising incomes, and urbanization, which is leading to the continuous expansion of the poultry industry. However, the industry is currently facing unprecedented challenges, especially for small-scale farmers and those who are economically disadvantaged, both in rural and urban areas. Poultry plays a crucial role in reducing poverty by providing income opportunities and market participation. During times of crisis, selling birds can act as a form of household insurance. Unfortunately, the growth of the market mainly benefits large-scale operations, putting small-scale farmers at a disadvantage in accessing the market. Additionally, poultry can pose a threat to human health by carrying infectious diseases and contributing to antimicrobial resistance. Furthermore, the poultry industry has a significant environmental impact and consumes substantial natural resources. Although it efficiently converts natural resources into food, it requires large amounts of land, water, and nutrients for feed production. This contributes to climate change and leads to air and water pollution.

In the future, policymakers in the Middle East, including Saudi Arabia, will place increasing importance on food security. Fiaz et al. (2018) discussed the crucial role of extension agents in promoting innovative technologies and raising awareness among the farming community to meet the country's dietary needs. Alamri and Al-Duwais (2019) conducted a study on some key components of food security in Saudi Arabia, such as wheat, barley, and poultry, as well as forecasted demand from 2017 to 2025. The study focused on the demand for these strategic commodities in KSA, with results showing a positive impact on wheat and poultry, which play a vital role in ensuring food security.

In the Kingdom of Saudi Arabia, several charitable assistance programs were established to support the growing number of low-income communities caused by the rising cost of living (Saudi Food Bank 2020). A recent study was conducted to evaluate the state of food security in the western province of the Kingdom, with a focus on low-income women. The findings of Hanbazaza and Mumena (2022) revealed that half of the low-income women lacked food security, forcing them to find other means to address the food shortage. This challenge can have adverse effects on their mental and overall health, as well as their overall life satisfaction in comparison to the group that has access to enough food.

The government is motivated to prioritize poultry production for food security based on three criteria. Firstly, poultry production consumes less water compared to red meat production (Daghir et al. 2018). Secondly, due to its qualities, investments in the poultry industry provide animal protein in a timely manner and enhance food security in the short term. Poultry production exhibits higher food transformation efficiency and fattening rate compared to other animal sources. Thirdly, chicken production is relatively cost-effective, involves fast capital turnover, and requires minimal space (Agricultural Development Fund 2019).

With regard to food security, poultry production enhances food security by providing a crucial source of protein in the form of meat and eggs. Meat and eggs are two essential components of a healthy diet and are often in high demand, especially in developing countries where people may not have access to other protein sources like red meat (Alraedah 2023). Additionally, poultry farming helps to create jobs along the poultry supply chain, from production to consumption. The creation of jobs assists those involved in the sector by providing a better income and therefore better access to food. It also promotes the consumption of poultry products in rural areas. Hence, poultry is closely linked to the accessibility and availability of food. Effective management and good practices in poultry farming result in the production of high-quality poultry products and reduce poultry loss and waste. These reductions not only contribute to sustainability but also decrease the environmental impact of the poultry sector. Furthermore, it is worth noting that poultry can be raised in diverse climatic conditions, providing a source of food and income for people residing in these areas. Compared to other livestock projects, the cost of poultry farming is relatively small. Moreover, poultry farming can help improve food security by enhancing access to food in rural areas. Poultry products, which are rich in protein and contain significant amounts of minerals and vitamins, play a crucial role in providing healthy food and are directly linked to the utilization aspect of food security. Poultry farms not only provide income at the individual or household level but also at the country level when poultry is exported to other countries, generating foreign currency or meeting local demand for poultry products and saving hard currency that would otherwise be spent on importing poultry products. Furthermore, poultry farming can be considered an anti-risk measure as it contributes to the diversification of agricultural production, which correlates with the stability pillar of food security. In conclusion, poultry production, whether as a backyard operation or on small or large farms, traditional or improved, has a direct connection to the pillars of food security.

3.2 The Importance of Chicken Meat for Human Health

Chicken meat is rich in desirable monounsaturated fats compared to the amount of less healthy saturated fats found in most cuts of red meat. Poultry meat is free from trans fats, which are known to cause coronary heart disease and are abundant in beef and lamb. A 2006 study conducted by the World Cancer Research Fund and Bingham found that consuming excessive amounts (over 500 g/week) of red meat, particularly processed meat, can be unhealthy. However, this study did not include chicken meat as a potentially harmful food.

Poultry meat is recognized for its low energy concentration and high nutrient density. It is an excellent source of high-quality protein, providing 20–22%. Additionally, it has lower amounts of iron and zinc compared to red meats. Poultry meat is also abundant in B vitamins including thiamin, riboflavin, niacin, and vitamin B6, while containing less vitamin B12 compared to other meats. Moreover, it has relatively lower amounts of vitamin E, pantothenic acid, folic acid, and biotin. Recent studies have shown that apart from vitamin D, the meat also contains 25-hydroxycholecalciferol metabolite, which is five times more active than calciferol (Ovesen et al. 2003; Barroeta 2007).

Poultry products help improve nutrition. The products of poultry projects in Saudi Arabia, such as eggs and chicken, are rich in nutrients like protein, iron, and vitamin B. This makes them an important component in achieving a balanced diet. Eggs are also a good source of choline, which is essential for brain function (Alraedah 2023). The nutritional value of poultry products for human health will be explained and thoroughly discussed in the subsequent sections below.

3.2.1 Source of the Protein

According to Kralik et al. (2017), chicken meat contains a high amount of amino acids which are essential for the development of human muscle protein. It is regarded as an easily accessible source of protein that is of high quality and also provides other important nutrients. To satisfy the increasing demand for high-quality protein from consumers, the poultry industry focuses on choosing fast-growing broilers that can attain a body mass of approximately 2.5 kg within six weeks of intensive feeding. Additionally, the composition of chicken meat can be altered by adjusting the chicken's diet, resulting in meat that is enriched with functional substances like n-3 PUFA, carnosine, selenium, and vitamin E. This makes chicken meat a valuable food item that not only possesses a high nutritional value but also contains beneficial components for human health (Kralik et al. 2017).

The fat content of cooked chicken varies depending on whether it is cooked with or without the skin, the portion of the bird, and the bird's diet and breed. Breast meat contains less than 3 g of fat per 100 g. On average, dark meat without the skin contains 5–7 g of fat per 100 g. Approximately half of the fat in chicken meat consists of desirable monounsaturated fats, while only one-third is less healthy saturated fats. In comparison, most cuts of red meat have higher proportions of saturated fats and vary in total fat content. Therefore, chicken meat is considered a healthy meat option. Unlike beef and lamb, chicken meat does not contain trans fats which contribute to coronary heart disease. In Canada, beef has been reported to have values of 2–5%, while lamb can have as high as 8% trans fats. The World Cancer Research Fund, along with other sources like Bingham (2006), has suggested that consuming large amounts (more than 500 g per week) of red meat, particularly processed meat, maybe unhealthy (FAO 2013).

3.2.2 Source of Vitamins and Minerals

Chicken is an important source of certain vitamins, such as vitamin D, that help in the absorption of calcium, ultimately leading to stronger bones. Additionally, vitamin A plays a role in improving eyesight, while B vitamins are necessary for generating energy and forming healthy red blood cells. Chicken also contains sodium and potassium, which contribute to balancing body fluids. Its phosphorus content helps regulate brain functions, maintain healthy bones and teeth, and enhance metabolism (Ahmad et al. 2018; Warren and Livingston 2021).

3.3 The Importance of Chicken Egg for Human Health

An egg is a food with low energy content that is economically beneficial and contains high-quality protein, as well as various important nutrients including folic acid, choline, iron, selenium, and vitamins A, B, D, E, and K. Eggs are also a rich source

Table 1 Types and functions of egg white proteins

Name	Action
Ovalbumin	The most significant proteins serve as a benchmark for comparison in biochemistry
Ovokinin	It has recently been discovered that it can dilate blood vessels, making it a potential treatment option for high blood pressure
Ovotransferrin	It has recently been discovered that it can dilate blood vessels, making it a potential treatment option for high blood pressure
Lysozyme	It is employed as an antimicrobial agent in various food items
Ovomucin	Prevent blood clotting caused by bacteria's β-subunit. It is toxic to cultured cancer cells that are glycosylated
Ovoinhibitor	Antitrypsin inhibits the activity of proteolytic enzymes in bacteria and mold
Cystatin	Medical applications include antimicrobial, antiviral, and insecticidal effects. They also include preventing cerebral hemorrhages and controlling the spread of cancer cells, though these applications are expensive
Avidin	It (referring to a specific protein) binds to biotin and has been widely used in molecular biology, biochemistry, and in ELISA assays

Source Abeyrathne et al. (2013, 2014)

of carotenoids, lutein, and zeaxanthin. They are a significant source of protein, with approximately 6–7 g of protein in one egg. The protein found in egg white is a standard for comparing with other food proteins (Réhault-Godbert et al. 2019). Egg white comprises important proteins such as ovalbumin (54%), ovotransferrin (12%), ovomucoid (11%), ovomucin (3.5%), and lysozyme (3.5%). These proteins are crucial and have importance in industrial applications if separated (Abeyrathne et al. 2013).

3.3.1 Types and Functions of Egg White Proteins

Abeyrathne et al. (2013, 2014) declared that egg white contains several functional proteins, as shown in Table 1.

3.3.2 Carbohydrates

The egg yolk comprises 1% carbohydrates. of that amount, 70% is composed of oligosaccharides, specifically mannose and glucosamine, which are bound to protein. The remaining 30% is in the form of free glucose carbohydrates. Yolk carbohydrates, such as Sialyloligosaccharides and Sialic acid (gangliosides), are crucial for the rapid growth of an infant's brain as they modify neural cell adhesion molecules (NCAM) (Wang 2009).

3.3.3 Egg Pigments

The egg yolk has the highest concentration of pigments, making up 0.02% of its dry weight. Chickens cannot produce carotenoids, which are responsible for the yolk's color, and therefore, they must obtain them from their diet. Yolk carotenoids can be divided into two groups: xanthophylls, which have a hydroxyl group in their molecules, and carotenoids that do not have this group (Kljak et al. 2021).

In study conducted by Dalle Zotte et al. (2021), the effects of various farming methods (cage, barn, organic) on egg quality traits were examined for marketing purposes. The results indicated that the physical characteristics and color of the eggs differed depending on the method employed, with organic eggs being the most notable. Specifically, organic eggs exhibited a distinct yolk color and nutritional composition.

3.3.4 Egg Fats

The yolk of an egg is mixed with bile salts to assist in the process of digestion, including for infants. The ratio of unsaturated fats to saturated fats is 1:2, which is highly beneficial. The primary unsaturated fat, known as oleic acid, does not have any negative impact on blood cholesterol levels. Poultry meat serves as a significant source of crucial polyunsaturated fatty acids (known as PUFAs), particularly omega-3 fatty acids. In comparison to other types of animal meats, chicken meat contains a higher quantity of important fatty acids. To fulfill the recommended daily intake (RDI) of niacin, adults can consume 100 g of chicken meat per day, while infants can do so with 50 g. By incorporating flaxseed, which is a supplement rich in n-3 PUFAs, into chicken, the amount of n-3 PUFAs in thigh meat can be increased from 86 to 283 mg/100 g, and in minced carcass from 93 to 400 mg/100 g (Bingham 2006; Barroug et al. 2021).

3.4 The Designer Eggs

Designer eggs are eggs that have been modified from the standard egg by the addition of vitamins, minerals, and omega fatty acids. This discovery was initially made by Miles in 1998. Omega-3 fatty acids, which are a type of polyunsaturated fatty acid, contain a double bond that is three atoms away from the terminal methyl group in their chemical structure (Sireesha and Prasanna 2019). Consuming omega-3 polyunsaturated fatty acids (PUFAs) can provide several health benefits. These benefits include reducing plasma triglycerides, blood pressure, platelet aggregation, thrombosis, and atherosclerosis. These findings were initially reported by an anonymous source in 2002. Brown-seeded flax (*Linum usitatissimum* L.) is an outstanding source of omega-3 unsaturated fatty acids, especially suitable for poultry feed (Cassiopaea

Forum 2009). Common varieties of flaxseed have high concentrations of polyunsaturated fatty acids, particularly alpha-linolenic acid. In 2010, Najib and Al-Yousef conducted an experiment to examine the effects of different levels of flax seeds on laying performance and fatty acid content in egg yolks. They fed 200 pullets, placing 5 birds per cage, with 0, 5, 10, 15, or 20% weight of flax seeds—either roasted or unroasted. Each treatment was repeated 5 times. The results demonstrated that feeding 10% roasted flax seeds led to higher levels of docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA), and alpha-linolenic acid (C18:3n3) in egg yolks. In contrast, feeding 5% or 15% unroasted flax seeds resulted in the highest levels of linoleic acid (C18:2n6) in the eggs. Including 15% unroasted flax seeds led to a relatively lower egg production rate but promoted an excellent omega-3 fatty acid profile in the eggs. In conclusion, adding 10% flaxseed to the feed is highly beneficial for egg production, while incorporating 15% unroasted flax seeds may be more advantageous for the omega-3 fatty acid content in the eggs (Najib and Al-Yousef 2010).

3.5 Healthy Eggs

In recent years, there has been a significant interest in consuming chicken eggs to obtain essential nutrients (Miles 1998). This is especially important for improving the nutrition of individuals with low income in developing countries since eggs are relatively inexpensive (FAO 2013). The process involves increasing the levels of certain nutrients, like folic acid, B12, and vitamin E, in the diets of hens. These nutrients are then passed on to the eggs. Two trace minerals that can also be increased in eggs are iodine and selenium. Iodine is necessary for the production of two hormones (T4 and T3) in the thyroid gland, while selenium is a powerful antioxidant that has recently gained attention (Surai and Dvorska 2001). Despite the controversy surrounding the belief that chicken eggs are unhealthy for humans due to their high cholesterol content (187 g) and saturated fat content (1.6 g), eggs actually contain significant amounts of important nutrients. These include folate, riboflavin, selenium, choline, vitamin B12, fat-soluble vitamins A, K, E, and D, as well as lecithin. Furthermore, eggs are an excellent source of high-quality protein (6 g) and pigments such as Lutein and Zeaxanthin, which are antioxidants that protect eye health. Additionally, eggs are the primary source of choline, which, along with Lutein, plays a crucial role in the development of the brain and nervous system in fetuses and newborns. Eggs also contain natural vitamin D, an important nutrient for bone health and immune support. Finally, it’s important to note that hens provide all the necessary nutritional components for the embryo to develop into a mature chick. Based on this information, it is clear that consuming eggs is particularly important for children and healthy adults. Recently, the Supreme Advisory Committee for Nutrition in the United States of America retracted its previous warning that foods containing cholesterol posed a threat to society (Farrell 2013).

4 Food Loss and Waste of Poultry Products in Saudi Arabia

One-third of food produced each year, which is suitable for consumption, is lost or wasted annually. In order to decrease food loss and waste, the Food and Agriculture Organization (FAO), along with other organizations, agencies, and associations, has been making significant efforts. They aim to raise awareness through educational campaigns and implement laws that will help reduce food loss and waste. Additionally, the formation of numerous food banks or charities has taken place, which are dedicated to reusing surplus food and distributing it to those in need. This initiative aims to prevent food loss and waste and preserve the environment. The FAO has also reported that the production costs of waste reach USD 750 billion annually. Food waste contributes to the problems of famine and food insecurity, which affected between 720 and 811 million people worldwide in 2020, an increase of 118 million compared to 2019 (FAO et al. 2021).

Saudi Arabia is considered one of the worst countries in the world when it comes to food waste. On average, each person in the Kingdom wastes between 200 and 500 kg of food, which amounts to roughly one-third of all the food that is wasted. This has significant economic implications and poses a threat to global food security. To address this issue, one of the main objectives of the Saudi Vision 2030 is to implement strategies for food security. In a recent study conducted by Alshabanat et al. (2021), different models were used to estimate the level of food loss and waste in Saudi Arabia. The findings revealed that food loss and waste (FLW) accounted for 33.1% overall, with food loss making up 14.2% and food waste making up 18.9%. Furthermore, their analysis projected that food loss and waste would decrease by 50% between 2020 and 2030.

Saudi Arabia is considered one of the worst countries in the world when it comes to food waste. On average, each person in the Kingdom wastes between 200 and 250 kg of food, which amounts to roughly one-third of all the food that is wasted. This has significant economic implications and poses a threat to global food security. To address this issue, one of the main objectives of the Saudi Vision 2030 is to implement strategies for food security. In a recent study conducted by Alshabanat et al. (2021), different models were used to estimate the level of food loss and waste in Saudi Arabia. The findings revealed that food loss and waste (FLW) accounted for 33.1% overall, with food loss making up 14.2% and food waste making up 18.9%. Furthermore, their analysis projected that food loss and waste would decrease by 50% between 2020 and 2030.

One-third of food produced annually, which is suitable for consumption, is lost or wasted each year. In order to reduce this issue, FAO, various organizations, agencies, and associations have been making increased efforts. This includes raising awareness through educational campaigns and implementing laws to decrease food loss and waste. Additionally, the formation of food banks and charities has helped in reusing surplus food and distributing it to those in need, thereby preventing food loss and waste and protecting the environment. In terms of poultry, the amount of loss and waste accounts for 29% of the available poultry for consumption.

Based on the Saudi Arabia Baseline for food loss and waste, the findings show that in poultry production, approximately one-third (29%) is lost or wasted. This can be further broken down into 13% food loss and 16% food waste. The overall loss and waste of poultry totals to 444 thousand metric tons, equivalent to a value of 2799 million SAR. When examining the poultry supply chain, roughly half of the total loss and waste occurs during the consumption stage (46%). This is followed by a 26% loss during distribution, 14% during handling and storage, 9.5% during production, and 4.5% during packing. These figures were obtained from the Baseline Study.

Results from the field survey indicate that health factors, such as the spread of viruses and bird diseases, as well as noncompliance with required product specifications, are the main causes of loss in the poultry sector. Inefficient workforce practices and failure to adhere to appropriate cooling conditions also result in the disposal of significant quantities of poultry meat (SAGO 2019a, b).

5 Production of Major and Medium Poultry Projects in Saudi Arabia

In Saudi Arabia it is expected that the production of chicken meat raised locally will reach 950,000 tons in the year 2022. This rise can be attributed to the expansion project of the National Poultry Farm (Al-Watania) in Al-Qassim, which is estimated to be finished by 2022. This expansion will introduce an additional 850,000 to one million chickens into the market. The Al-Youm Chicken Company, a division of the Almarai Group, has recently disclosed a noteworthy expansion plan totaling $1.8 million.

It has been observed that most of the increase in production is because of large companies operating in the country. However, medium-sized companies like The Agricultural Development Company, Intaj, and Aseer, as well as small companies like Radwa and Golden Chicken, have also contributed to this increase. It is important to note that the main source of poultry meat production in the country is broiler chicken. Quail represents a small percentage of 1500 tons a year from Astra farms in Tabuk, located in the northern region of the country. The expansion in production is believed to be a result of government support and decreased mortality rates. The decrease in mortality rates among poultry has had a significant impact on the increase in production. Poultry companies, especially larger ones, have strictly followed biosecurity measures to reduce the risk of disease. As a result, the average mortality rate has decreased from 25% to less than 6% in recent years. Some projects that implement these measures well have demonstrated a mortality rate of 2.5% or less. This has helped increase production while significantly reducing overall costs.

According to Mousa (2020) currently, chicken meat production in Saudi Arabia is mostly controlled by about ten vertically integrated companies. Three major companies, namely Al Watania, Fakieh, and Alyoum, along with seven medium-to-small-sized farms, have control over up to 95% of the production. Poultry farms can be found in twelve different provinces in Saudi Arabia, but only six provinces contribute to 88% of chicken meat production. In the year 2020, the Al-Qassim province, where Al Watania Poultry Farm is located, accounted for approximately one-third of the total chicken meat production in Saudi Arabia. Makkah and Riyadh each contributed 15%, followed by Aseer and Hail, which contributed 13% each. Over time, there has been an increase in the percentage of chicken meat produced in the Hail province due to the expansion of Almarai's Alyoum Poultry Farm.

6 Efforts to Improve Poultry Sector in Saudi Arabia

The Ministry of Environment, Water, and Agriculture has reported good news regarding poultry production in the Kingdom of Saudi Arabia. In 2021, the production of poultry amounted to 910,000 tons, and it is expected to increase significantly in the coming years due to the expansion of the National Company's chicken projects in Qassim. This company is the largest poultry producer in the Kingdom and one of the largest in the world. A major factor contributing to the increase in production is the significant decrease in broiler chicken mortality from 25% ten years ago to less than 6% today. In 2020, the domestic production of Saudi Arabia reached 60% of self-sufficiency, and plans are underway to increase this level to more than 85% by 2030 in collaboration with the private sector. The Saudi government aims to facilitate producers' access to land for broiler chicken farms, provide loans to purchase equipment, and improve the feed support system to achieve this goal. Furthermore, the import of chicken meat to Saudi Arabia decreased from 617,930 tons in 2020 to 520,000 tons in 2021, a decrease of 16%. The Saudi Food and Drug Authority prevented imports from 11 major poultry export companies in Brazil, leading to this decrease. However, it is expected that the percentage of imports will increase by 4% in 2022 to reach 540,000 tons, as the largest Brazilian company in the field of broiler chicken production has gathered large resources to increase its exports to the Kingdom.

According to the Ministry of Environment, Water and Agriculture (MEWA) (2022) the government of the Kingdom of Saudi Arabia, specifically MEZWA and the Agricultural Development Fund (ADF) provides unmatched financial support for the development and expansion of the poultry sector. They offer financing for up to 70% of the capital required for modern technology projects in the poultry sector, as well as granting government lands for these projects. The goal of these initiatives is to increase the self-sufficiency rate of poultry meat to over 65% in the near future. The poultry sector has received more than 665 million riyals of support through agricultural subsidies, according to the last official announcement by the Ministry in January 2021. These subsidies aim to strengthen the food security system and encourage new investments in the Saudi poultry industry. The MEWA is targeting an annual production of 1.3 million tons of broiler chickens to ensure national food security, increase local content, and generate employment opportunities. Saudi Minister of Environment, Water and Agriculture, stated that this effort follows a significant increase in self-sufficiency in poultry meat from 45% in 2016 to 68% in 2022. The MEWA has established six goals for the poultry sector, including increasing the number of licenses and expanding investment operations to meet growing demand and achieve self-sufficiency. These goals also involve boosting the macro economy and attracting new investors, creating job opportunities for local individuals, empowering women in support services within the sector, and achieving rural development (MEWA 2022).

The Ministry of Environment, Water, and Agriculture (MEWA 2022) has announced a plan to expand the broiler chicken sector and support services in collaboration with relevant authorities. The objective is to increase the self-sufficiency rate of poultry meat to 80% by 2025, which is the first step in achieving food security. This plan will attract new investments worth SAR 17 billion ($4.5 billion) to the poultry production sector in the Kingdom, resulting in a target production capacity of approximately 1.3 million tons of broiler chicken per year. The plan aims to achieve food security and create job opportunities. MEWA has confirmed that over SAR 56 million will be provided in the eighth support cycle for the poultry sector as part of the agricultural subsidy program, which aims to assist this vital sector. The program has totaled more than SAR 430 million and is one of the wise leadership's initiatives to maintain local food security, with the poultry sector being one of its critical contributors. The poultry sector includes broiler chicken products, table eggs, broiler chicks, parent stocks, and laying hens. The support program aims to enhance food security in the Kingdom by supporting local product to meet the increasing demand. It is important to note that the self-sufficiency percentage in poultry meat has risen from 45% in 2016 to 68% in 2022 (Bulletins 2019; Mousa 2020; MEWA 2022).

According to the USDA Foreign Agricultural Service (2021) and Mousa (2020) Chicken meat production is expected to continue to increase as the Kingdom aims to achieve 80% self-sufficiency by 2025. Currently, the percentage is already over 60%. Saudi chicken meat production in 2020 is estimated to be 930,000 mt and is projected to rise to 950,000 mt in 2021. It is anticipated that Saudi chicken meat imports will reach 550,000 mt in 2020 and are expected to reach 625,000 mt in 2021. Brazil is the main supplier of poultry imports to Saudi Arabia, and Saudi Arabia is the second-largest export market for Brazilian chicken meat. The Saudi ban on electric immobilization continues to prevent the United States from exporting chicken meat to Saudi Arabia.

The Agricultural Development Fund is a credit institution run by the government that specializes in financing various agricultural activities across all regions of the Kingdom. Its purpose is to support and improve the agricultural sector by utilizing modern scientific and technical methods to increase productivity. The fund provides credit services to help achieve the strategic agricultural and water goals of the Kingdom. It has recently launched a new strategy that aligns with the policies of the Ministry of Environment, Water, and Agriculture to contribute to the implementation of the Agricultural Strategy (Fiaz et al. 2018).

7 Conclusion and Prospects

The poultry industry is considered one of the important industries that Saudi Arabia has paid great attention to. This is because it plays a significant role in achieving food security for Saudi society and directly impacts the lives and health of citizens. The poultry sector contributes to providing food that is rich in protein and also serves as a source of income for various segments involved in the supply chain of poultry products. This includes production, processing, cold storage, handling, transportation, and consumption, as well as supporting sectors involved in poultry production, such as feed manufacturing, veterinary medicines, and the manufacturing of poultry farms. The Ministry of Environment, Water and Agriculture, in collaboration with the Agricultural Development Fund and large companies specialized in poultry products, has developed multiple expansion plans to increase the production of poultry meat and eggs. This is done in order to achieve target self-sufficiency by 2030 and to meet the Saudi demand for these products. In order to succeed in this sector and achieve the objectives of the agricultural strategy and the Saudi food security strategy, it is necessary to have the combined efforts of the private sector, large poultry product companies, and owners of medium and small farms to attain these targeted levels of self-sufficiency for the Kingdom in poultry products.

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Chapter 8
Contribution of Sustainable Fisheries and Aquaculture to Food Security in Saudi Arabia

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Abstract The prominence of aquaculture and fisheries towards nutrition and food security in the present and future is influenced by a complex interplay of environmental, development, policy, and governance challenges. At present, Saudi Arabia is regarded as one of the prime water-stressed nations among the world. Extreme temperatures, low precipitation, inadequate arable land, the absence of productive soils, and dwindling water resources characterize the tough physical environment of the kingdom. Rapidly growing population and excessive extraction of groundwater continue to stress the prevailing water resources. Furthermore, it is anticipated that global climate change will have adverse effects on water resources and agricultural systems that are already depleted. As a result, potential for the enhancement of agriculture sectors particularly fisheries or aquaculture production systems to meet increasing demand of foods are extremely inadequate, despite the fact that majority of the current demand is being met through imports. It is expected that by the year 2050, Saudi Arabia will have to import all of the goods it requires. In the meanwhile, there is a wide variety of technology that can help to save land and water, and it has the ability to contribute to the production of enough energy to meet the needs of the home market. Therefore, the extension agent's role is crucial in promoting innovative technologies and educating the agricultural community so that the recommendations can be put into practice to satisfy the dietary requirements of the nation. Considering this, the current chapter demonstrates convincingly the necessity to strengthen the fisheries and aquaculture production systems so as to ensure food security and combat climate change.

Keywords Aquaculture · Fisheries · Agriculture · Food security · Climate change · Saudi Arabia

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1 Introduction

Aquatic foods play a vital part in nutrition and food security, serving as an exclusive and diverse source of essential omega-3 fatty acids and bioavailable micronutrients, also to being a significant source of protein (Ariño et al. 2013; Maulu et al. 2021; Sun 2008). Aquatic diets, which are mostly derived from the marine and freshwater organisms, have been prized for a long time as an excellent source of animal protein and an important part of healthy diets (Berrazaga et al. 2019; Farmery et al. 2020; Maulu et al. 2021). Integrating and prioritizing aquaculture and fisheries goods into global, national, and regional food system strategies and policies considered as a critical component of our agrifood system transformation (FAO et al. 2021). It is an imperative and ongoing societal challenge to sustain the continuous production and supply of aquatic foods from aquaculture and capture fisheries (Boyd et al. 2022). For long-term provision, the production of aquatic foods must be environmentally, socially, and economically sustainable in addition to being safe, nutrient-dense and sufficient to meet preferences and demand (FAO 2020). An environmentally friendly sustainable production is thus desirable to keep the diversity and productivity of the food resources and the ecosystems that support it and to make sure that the effects of food production systems do not hurt other services of the ecosystem (Grindle et al. 2015; Zezza and Tasciotti 2010).

In recent years, the significance of food security has become more apparent owing to the periodic disruptions in food production systems and supply chains brought about by key elements like economic crisis, country conflicts and climate change (Fiaz et al. 2018). These issues elicited the global food price index (FPI) skyrocketed to a new all-time high value of 159.7 points in May 2022 (FAO 2022). It is expected that the cost of foodstuffs will continue to escalate at an exponential rate due to the ongoing conflict between Russia and Ukraine, two of the world's leading suppliers of food commodities. In addition to these concerns, the trend of rising fuel prices following the COVID pandemic has speeded up (Bloem and Farris 2022). This has had a further impact on food transportation costs, also known as food miles (Li et al. 2022; Li and Song 2021). While an increase in food prices may also be a reflection of a country's economic development, developing economies and countries that rely heavily on imported agricultural products are unable to meet the food demand in coming years (Mok et al. 2020). This raises the concern of food security, which affects not only food availability but also water security and the nutritional quality of the foods, importing agricultural products is therefore not a sustainable solution (Armanda et al. 2019; Grindle et al. 2015; Selvanathan et al. 2015). Local food production and supply, on the other hand, turns into a noteworthy challenge and in several cases, it is impossible due to the unsuitable conditions set off by water scarcity, arid climate, soil degradation, energy crisis, urbanization, population growth, and climate change (Rothwell et al. 2016; Zezza and Tasciotti 2010). To solve these problems, agricultural methods, techniques, and research should be given top priority to assure sustainable and effective farming methods that make the optimal usage of energy and natural resources, which is adjacent to the market to assure food security and reduce food miles, to create high quality, safe and nutritious products (FAO 2022).

In the coming decades, the global demand for food derived from aquatic environments is anticipated to increase, as these meals are crucial for helping to meet the demands of expanding human population (FAO 2022). The world's population is projected to rise 2.4 billion in 2050, reaching 9.7 billion (FAO 2020). Due to the emergence of a greater proportion of 'middle-class' individuals with greater purchasing power and a propensity to consume more animal protein than those with lower incomes, therefore food demand is anticipated to increase more rapidly than population growth (Dasgupta and Robinson 2022).

The societal significance of aquatic food differs greatly on a local, regional, national and global scale, and food production methods are diverse (Burger et al. 2014). Similarly, the consequences of growing global demand of food will differ from country to country and from person to person within each country, depending on how dependent they are on aquatic food sources and how easily they can obtain such sources (Maulu et al. 2021). Although it is almost certain that some nations will achieve food security, in which majority of the population possesses social, physical, and economic access to adequate, safe, and nutritious foods which satisfies their dietary needs and preferences for a dynamic and healthy life at all times, however, some other nations will not be able to achieve this goal (Al-Kandari and Jukes 2012; FAO 2022). The sustainability, variety, safety, and sufficiency of domestic production; the performance of supply chains; the ability to import and export, and the equity of food distribution all play important roles in determining aquatic food security for any nation (Golden et al. 2021).

Over three billion individuals get about 20% of their daily recommended amount of animal protein from fish (Maulu et al. 2021). Over the past few decades, the proportion of fish consumed by humans has increased to 86%, with the remaining 14% going toward other uses such as the manufacturing of fish meal and oil, both of which indirectly aid in the creation of food for humans (FAO 2020). According to the "Seafood—Global Market Trajectory and Analytics" 2022 report, the global market for seafood is projected to grow at a Compound Annual Growth Rate (CAGR) of 2.9% and touch USD 134 billion by 2026. In 2022, the market was estimated to be worth 116.8 billion USD. The United States has always been a major consumer of seafood, but the report states that the rise in seafood production is due to rising demand in East, South, and Southeast Asian nations such as India, China and others. By 2030, it is likely that more than 80% of the seafood eaten in the world will be from the developing countries (Béné et al. 2015).

Global fish production has increased rapidly over the last two decades and now exceeds beef production (FAO 2020). Though production from aquaculture is growing, production from wild capture has largely stabilized due to a lack of possibilities to improve fishing practices or increase catch rates. Aquaculture output is thus anticipated to surpass wild capture production in the near future (Boyd et al. 2022). Among the world's fish stocks, the FAO (2012) reported that 61% were exploited to their maximum sustainable level in 2011, while 29% were overfished and barely 10% were underfished. Despite the fact that the oceans are already overfished (Sumaila et al. 2011), some researchers (such as Boyd et al. 2022; Costello et al. 2020) suggesting that marine aquaculture in conjunction with sufficient conservation actions could enable the sea to deliver ample protein resources for humans in near future. However, using the methods that are currently in use for fishing, there is a very small likelihood of boosting wild capture (Costello et al. 2020).

Production patterns in aquaculture and capture fisheries around the globe show substantial geographical differences (Issifu et al. 2022). Capture production has declined in Europe; however, this has not been fully offset by an increase in aquaculture. Asia, on the other hand, exhibits a gradual increase in capture productivity complemented by a substantial increase in aquaculture production. In terms of global aquaculture production, Asia currently accounts for the vast majority (Golden et al. 2021).

Saudi Arabia, occupies about 75% of the Arabian Peninsula, is home to 34 million people (including over 12 million foreign residents) and features land cover of approximately 21,496,960 km^2 (FAOSTAT 2022). It has a coastal line of 2640 km and borders the Red Sea on the west and the Arabian Gulf on the east. Saudi Arabia is well-known for its extensive oil reserves, which constitute a quarter of the world's total therefore, petroleum and related industries dominate Saudi Arabia's economy (Cappelen and Choudhury 2017). Increasing economic diversification in Saudi Arabia has contributed to the expansion of food production sectors particularly, the fisheries and aquaculture sector has expanded rapidly in recent periods, propelling the nation to become an important regional producer and exporter of fishery products worldwide through the implementation of the maximum safety in production, high traceability standards, cutting-edge technology, and rigorous biosecurity (MEWA 2021).

Four million people lived in Saudi Arabia in the year 1960 (FAO 2012). It has surpassed 34.8 million as of 2020 and is projected to outstrip 56 million by 2050 (Baig et al. 2019). In order to feed a rapidly expanding population in a country with harsh environmental conditions and limited water resources Saudi Arabia imports more food to meet demand (Memon et al. 2022). In the year 2020, Saudi Arabia had the seventeenth biggest fish and seafood market size (1.24% market value share) in the world. Saudi Arabia was the 34th largest fish and seafood importer in the world in 2020, with USD 6847 million in imports (Euromonitor International 2021). From 2016 to 2020, the value of Saudi Arabian imports increased at a CAGR of 2.23% (Euromonitor International 2021). As a capital-rich nation, Saudi Arabia possesses considerable purchasing power on the international food market hence less susceptible to fluctuations in food prices than other countries that import significant amounts of food. Still, global population growth, climate change, and other factors like the COVID-19 pandemic are making the international food supply chain less stable, which makes the Saudi Arabian food security situation less certain (Sobaih 2020).

In order to achieve long-term, sustainable food security, it is imperative to place a priority not only on the reliability of supply chains but also on food safety, standardization, and education. There are grave concerns regarding the health and nutrition of the KSA populace in comparison to other nations in the Middle East and North Africa region, the obesity and diabetes rates in Saudi Arabia are among the highest (Fiaz et al. 2018). There has been an exceptional increase in non-communicable diseases like cancer and cardiovascular issues, coinciding with a shift to diets containing excess sugar, salt, and saturated and trans fatty acids which puts heavy stress on Saudi Arabia's economy and healthcare system (Baig et al. 2019; Grindle et al. 2015; Khan et al. 2017; Sultan and Haque 2018). In addition, the Saudi Arabian food industry is one of the most vulnerable to the dangers posed by global environmental change caused by human activities (Baig et al. 2022). It is anticipated that the Saudi Arabia, which is predominantly composed of arid and semi-arid desert, will experience increases in temperature that are even higher than the increase in the average temperature across the globe (Afzal et al. 2016). Furthermore, along with sea level rise, significant changes in the nation's rainfall patterns are also predicted (Alharbi et al. 2017). In the absence of any form of intervention, the impacts of human action on the environment will have the effect of further restrict agricultural capacity in a nation where traditional field agriculture is already hampered by a lack of water and by harsh environmental conditions (Baig et al. 2022).

The aim of this chapter is to deliver a comprehensive outline of the aquatic food system in Saudi Arabia, the barriers to food security, and possible solutions to ensure that people get access to the adequate quality and quantity of aquatic foodstuff while protecting the production systems and environment. To deliver a comprehensive analysis of the food system, we incorporate information about aquaculture, fisheries, health, animal and human welfare, as also environmental and safety issues. Because aquatic foods are considered one of the most widely traded commodities in the world, Saudi Arabia plays a vital role in a vibrant global network of consortiums that produce, process, and trade these foods. As a result, the accessibility of aquatic foods in the Kingdom can be significantly impacted by supply and demand dynamics from both the domestic and international markets. Throughout our analysis, we highlight problems relating to aquatic food security that are relevant to other relatively wealthy nations as well, particularly the Gulf Cooperation Council (GCC), Europe, and other regions where imports account for a substantial portion of national consumption.

2 Overview of the Fisheries and Aquaculture Sector in Saudi Arabia

Fish farming in Saudi Arabia received a boost in the late 1980s, and both the capture fishing and aquaculture industries have grown steadily since then. It is widely acknowledged that the fisheries and aquaculture sector play an important role for the food security of the Saudi population, despite the country's annual fish consumption being about 11.5 kg per capita, as opposed to 20.5 kg per capita in the international context (FAO 2020). During the period 2015–2017, captured fish dominated the total fish production in the kingdom, which averaged 68 thousand metric tons (mt). Capture fisheries contribution increased from 49,080 mt in 2000 to 67,511 mt in 2019

(FAO-GFCM 2021). The annual growth rate of 1.69% was greater than the global average but less than the Western Asia average (FAO 2020). The production was entirely contributed by marine fisheries, in contrast to the shares of inland fisheries in Western Asia and the rest of the world, which are 4.1% and 12.9%, respectively, inland fisheries had no contribution to Saudi Arabia's capture fisheries (Hassanien 2021). The taxonomic composition of the wild catch has not altered significantly, with a slight increase proportion of crustaceans and a marginal decline in marine fishes are reported in 2019 (Shellem et al. 2021). In 2010, there were 29,000 fishermen operating small boats in shallow coastal waters and larger artisanal fishing vessels in deep sea. In 2010, they constitute the largest fishing fleet with around 11,200 vessels. According to data compiled by the General Authority for Statistics (Table 1), the total catch from the Arabian Gulf and Red Sea in 2020 was 64,720 mt, a 2.2% decrease from 2019. In 2020, the Arabian Gulf catch contributed for 64.8% of the Kingdom's total catch. The traditional marine fisheries account for 91.1% of the kingdom's total capture. Jazan is the most important region for traditional fishing in the Red Sea, which accounts for 44.0% of the catch (7511 mt). The traditional boats accounted for 98.5% of all fishing vessels in the kingdom, the highest proportion of any type of vessel. The Red Sea coast accounted for 80.2% of the total number of boats on the Kingdom's coasts (Berumen et al. 2019). Regarding the workforce in marine fishing in 2020, there were 30,257 workers, of which 70.9% were fishermen and 17.2% were Saudis. 29.0% of the total workforce in marine fisheries were fishermen (General Authority for Statistics 2020).

It is estimated that the seafood consumption in Saudi Arabia is likely to grow by 8% per annum until 2030 as a result of the continued growth of the population (Foodex Saudi 2023) (Fig. 1). As a result of these trends, coupled with stricter safety regulations proposed by the governmental agencies, it is likely that the Saudi Arabia will become a major supplier of seafood in the near future because of its extensive coastline. For the past several years, Saudi Arabia is considered to have set the highest standards when it comes to fish farming and imports.

Table 1 Key indicators of marine fisheries in Saudi Arabia

Indicators	Unit	2016	2017	2018	2019	2020
Total catch from marine fisheries	mt	66,538	66,401	68,003	66,206	64,720
Number of fishing boats	Number	10,054	9224	10,944	10,929	10,697
Number of workforces	Number	24,466	28,043	30,370	30,332	30,257
Total amount of import of fish and shrimps	mt	160,570.2	155,047.1	138,044.9	156,729.4	123,028.3
Total amount of export of fish and shrimps	mt	48,283.5	61,104.3	69,482.2	39,677.6	27,847.8

Source Compiled by the author based on marine fishing statistics data from General Authority for Statistics (2020)

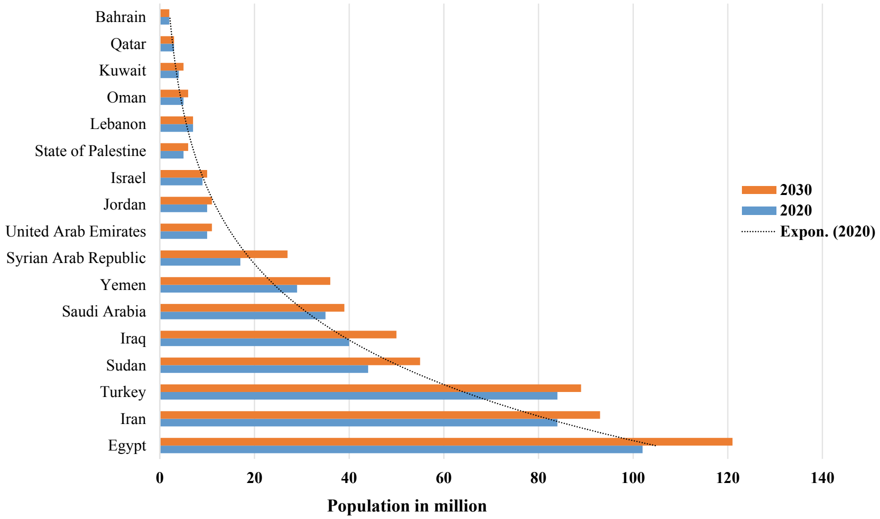

Fig. 1 Population forecast for Saudi Arabia and neighboring nations (2020 vs. 2030). *Source* Compiled by the authors based on data from United Nations world population prospects (2021)

Figure 2 provides an overall image of the fisheries and aquaculture production of major Middle Eastern nations. The information was obtained from the 2015 FAO fisheries Balance Sheet. Even though the data is from 2015, it can be used as an indicator to determine the amount of fisheries and aquaculture production in Saudi Arabia relative to other countries.

A report from the World Bank collection of development indicators (2021) states that Saudi Arabia contributed to a total fish production of 161,849 metric tons in the year 2020 as a result of the abundant fisheries resources exists along its two coasts. By implementing the National Fisheries Development Program (NFDP), Saudi Arabia further aims to develop its fisheries industry and produce 600 thousand mt of fish products by 2030. In addition, the National Visions 2030 plan to raise local fish consumption from its current 11.5 kg per capita in 2019 to 20 kg per capita by 2030, bringing it in line with global consumption levels (Vision 2030). Therefore, it is crucial to boost domestic output while protecting marine ecosystems. Even with increased efforts to boost domestic production, total fish product imports in 2019 approximately reached 210,000 tons (General Authority for Statistics 2020).

Saudi Arabia's coastline is home to an array of fish species and other marine organisms. Nevertheless, several factors such as Temperature fluctuations, sea-level rise, climate change, salinity changes, alteration in oxygen levels, increasing intensity and frequency of storms, rainfall and freshwater inflows, ocean acidification pose varieties of threat to these resources (Sumaila et al. 2011; Wabnitz et al. 2018; Sumaila and Tai 2020; Gokul et al. 2020). Numerous studies have examined climate change's impact on fish production in various ways. One of these is to use mockup simulations to detect potential climate change issues on fishery and fish production

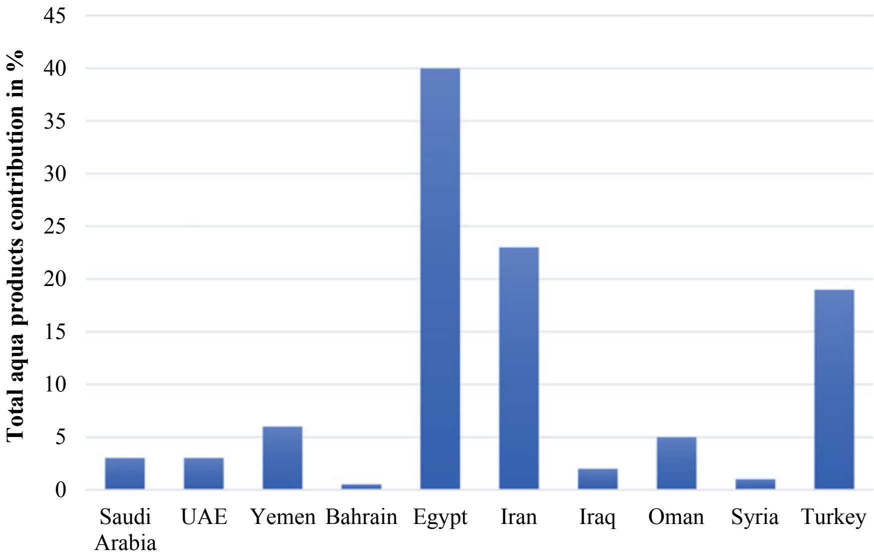

Fig. 2 Fisheries and aquaculture contribution (%) by countries in the Middle East. *Source* Compiled by the authors based on data from FAOSTAT (2022)

systems (Lam et al. 2012; Cheung et al. 2013; Wabnitz et al. 2018; Maulu et al. 2021; Suh and Pomeroy 2020). In light of these studies, it can be concluded that productivity of few fish species may likely to improve in the future, however the overall production from the capture fisheries tends to decrease significantly in the coming decades. Furthermore, the global fishing industry may be redistributed with increases in fish production in certain regions and decreases in other areas (Cheung et al. 2013; Blanchard et al. 2017; Lam et al. 2016). Climate change will have a significant economic consequence on the fisheries sector, resulting in job and revenue losses from the fisheries industry (Blanchard et al. 2017). Highly impacted regions, like West Africa, are predicted to lose 50% of their jobs, with a loss of income of USD 311 million per year (Lam et al. 2012). Consequently, several studies predict a 35% drop in returns globally (Lam et al. 2016).

Despite its geographical location, Saudi Arabia, along with the other middle east nations are susceptible to changes in climate and environmental factors. Predicted increases in average temperatures as well as sharp reductions in precipitation might be considered as two of the most important changes to affect the region in the near future (Al-Maamary et al., 2017a, b). According to a previous study in this area, climate change will likely lead to an additional decline of many important species, with a 35% drop projected in 2090 as compared to 2010 (Wabnitz et al. 2018). The expected decline in fish catch in Arab Gulf regions may, however, vary across the region, resulting in reductions of 26% or higher in the future (Tesfamichael and Rossing 2016).

Marine shrimp is the most widely farmed species in the country, although an epidemic of viral white spot disease in 2011 caused production to drop to below 16 thousand mt from a peak of around 26 thousand mt in 2009 and 2010 (Khan et al. 2017). Total production increased from 21 thousand mt in 2012 to 30 thousand mt in 2015, a gain of 26% over 2014 (FAO 2019). Biosecurity rules at the farm level and a national surveillance program were implemented, and production began to rise again after the target species was switched from native species *Fenneropenaeus indicus* to the more resilient *Litopenaeus vannamei* (non-endemic species). Consequently, the amount of food obtained from aquaculture has more than tripled, reaching 75,400 mt in 2019. The 14.25% increase in yearly growth rate was more than the regional and global norms (FAO 2020). Many huge farms have recently been established along the Red Sea's coastline, specializing in the marine cage cultivation of exotic species like the Asian seabass (*Dicentrarchus labrax*) and the gilthead seabream. Cage farming of marine finfishes, such as grouper and amberjack, is also gaining popularity.

In recent years, the exports and imports of fish and fishery products have been on the rise in Saudi Arabia. The value of Saudi Arabia's exports of fishery products has raised from 8.366 million USD in 2000 to 141.493 million USD in 2019 (FAO 2020). The 16% annual growth rate was higher than the sub-regional, regional, and worldwide norms (Euromonitor International 2021). Furthermore, the Saudi Arabian market for aquatic products grew at a faster rate than the global average, but at a slower rate than the comparable market for Western Asia (10.4%). As a result, Saudi Arabia's imports of fish products grew from 109.301 million USD from 2000 to 716.31 million USD in 2019 (Euromonitor International 2021). The European Union recognizes Saudi Arabia as a reliable supplier of aquatic products also; countries like United States, China and Japan are regular recipients of farmed shrimp exports. As the only producer of fish feeds in the GCC, Saudi Arabia stands alone. However, Saudi Arabia's fisheries output is lower than that of some of the GCC region's smaller states, while the country's aquaculture production gives it a significant advantage, leaving United Arab Emirates and Oman reliant on it (Al-Maamary et al., 2017a, b).

2.1 Development of Seafood Farming

Saudi Arabia has been practicing aquaculture for over four decades. The MEWA (Ministry of Environment, Water, and Agriculture) in collaboration with FAO and the White Fish Authority (WFA) of the UK conducted studies in order to identify potential species suitable in fresh and marine waters. Although the Nile tilapia was the first introduced aquaculture candidate in the country and raised in the inland ponds during early 1980s, it was the semi-intensive culture practices of shrimp species that propelled the sector to international prominence (Young et al. 2021). During the end of 1980s, the first experimental shrimp farm was set up along the Red Sea coast. A major commercialization phase began in the mid-1990s with the introduction of tiger prawn *Penaeus monodon* and Indian white shrimps *Fenneropenaeus indicus* (Papageorgiou 2020). Later, industry moved to the more resilient species *Litopenaeus* *vannamei* in 2014, as a result of the spreading epidemic of white spot syndrome virus (WSSV) in different parts of the world. However, despite a higher level of advancements, due to the favorable environmental conditions of the Red Sea coast and the use of advanced technologies in seafood farming, the sector has experienced a slow growth rate over the past few years. Due to this fact, aqua farming considered to be a developing industry in Saudi Arabia (FAO 2019).

Jeddah Fisheries Research Center (JFRC) was established in 1982 in collaboration with FAO and declared as a major center for aquaculture and fisheries research as well as a focal training point for personnel involved in the industry's capacity-building efforts. Several visionary entrepreneurs have made significant investments in the industry over the years, bringing knowledge, developing expertise, and building and installing cutting-edge facilities. In the early 2010s, fish cage aquaculture projects were launched alongside shrimp farming, with two important aquaculture candidates, Asian seabass and Mediterranean seabream being introduced for farming (Papageorgiou 2020).

The year 1995 assumed significance as shrimp farming emerged as an industry in Saudi Arabia. Initially, Indian white shrimp were cultivated under semi-intensive production conditions. The production results were considered positive in terms of growth rate, survival, and flesh quality. Since then, large-scale commercialization has taken place in order to produce shrimp products of premium quality for international the markets. The KSA's shrimp farming industry developed in two areas along the Red Sea coast: Jizan in the south and Al-Lith in the north. Both regions have excellent water quality and are ideal for shrimp farming (Bogorodsky and Randall 2019).

Aquaculture is now regarded as a vibrant food production segment and an important pillar in the Saudi Vision 2030, a strategic proposal to transform the economy, society, and the nation. Marine farming considered part of the agriculture sector contribute a share of 4.8% to the Saudi Arabian Gross Domestic Product (GDP) employing around 500 thousand workers (USDA Foreign Agricultural Service 2009). Based on this Fig. 3, Saudi Arabia believes that this industry will become self-sufficient along with other agricultural products such as eggs, milk, and dates (Papageorgiou 2020). In 2019, the FAO reported 75,400 mt of aquacultured products (Fig. 3), including shrimp, freshwater fish, and marine fish with respective shares of 80.6, 12.2, and 7.2%. Nevertheless, imports of important food items continue to remain high at 70% from 150 countries despite the best efforts bringing a decline in food imports (Al-Kandari and Jukes 2012). This could be due to a lack of a well-targeted development strategy that benefits smallholders as well as the major private sector.

2.2 *Seafood Utilization Trends*

Even though there are two long coastlines in the region (Arabian Gulf and Red Sea), there is a limited quantity of fish available locally. During the period from 2014 to 2020, it is estimated that between 60 and 70 thousand mt of fish products were

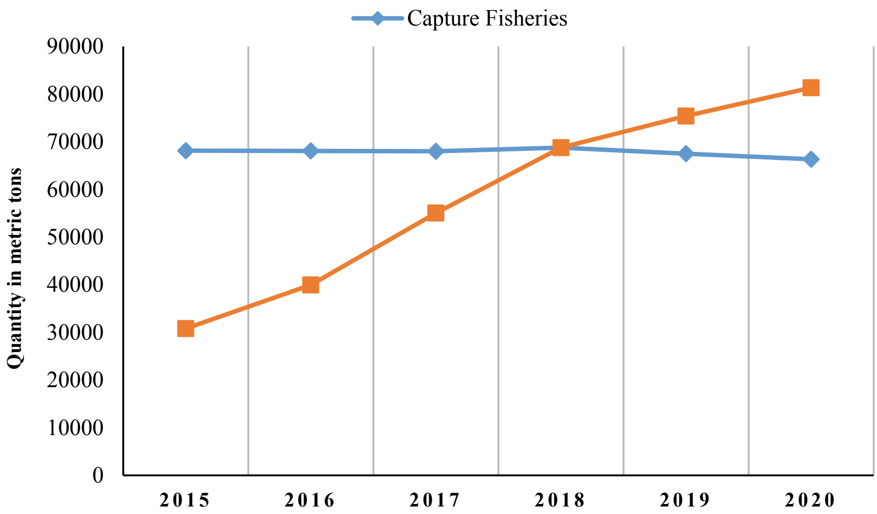

Fig. 3 The total capture and aquaculture production in Saudi Arabia in mt. *Source* Compiled by the authors based on data from FAO (2021)

landed yearly at the major ports of the country (Fig. 4), primarily by small coastal vessels operated by artisanal fishermen's (General Authority for Statistics 2020). The government efforts to stop overfishing and rationalize the fishing fleet resulted in a catch of 65,000 metric tons in 2020, 99.4% of which were caught by traditional fishing methods (Almahasheer and Duarte 2020). In contrast to landings from wild fisheries, local aquaculture production has improved substantially in recent times. It was estimated that aquaculture production exceeded catches from capture fisheries in 2018, with more than 75,000 mt of fish and shrimps produced, representing the growth rate of 200% over a three-year period (FAO 2020). Currently, shrimp is the predominant output of the aquaculture industry of Saudi Arabia, as the major portion of harvested shrimps are exported while most aquacultured fish are consumed locally (Khan et al. 2017).

Although aquaculture increased supply, imports were still a significant portion of the domestic market. Imports of fish and shrimp totaled 123,028 mt in 2020, a decrease of 21.5% compared to 2019 (General Authority for Statistics 2020). In the same year, total exports totaled 27,847 mt, a decrease of 29.8% compared to total exports in 2019. In 2020, the re-exports (export/imported goods, typically after they have undergone further processing or manufacture) totaled 5799 mt, a decrease of 11.2% from 2019 (Fig. 5). Over the last five years, the imports of seafoods accounted for more than 75% of local consumption have declined by an average of 2.6% as a result of the strict assessment and control actions implemented by the SFDA (Saudi Food and Drug Authority) in an effort to improve the safety and quality standards, as well as reduce dumping, and mitigate the risk of biosecurity issues related with food stuffs originates from some nations (Euromonitor International 2021).

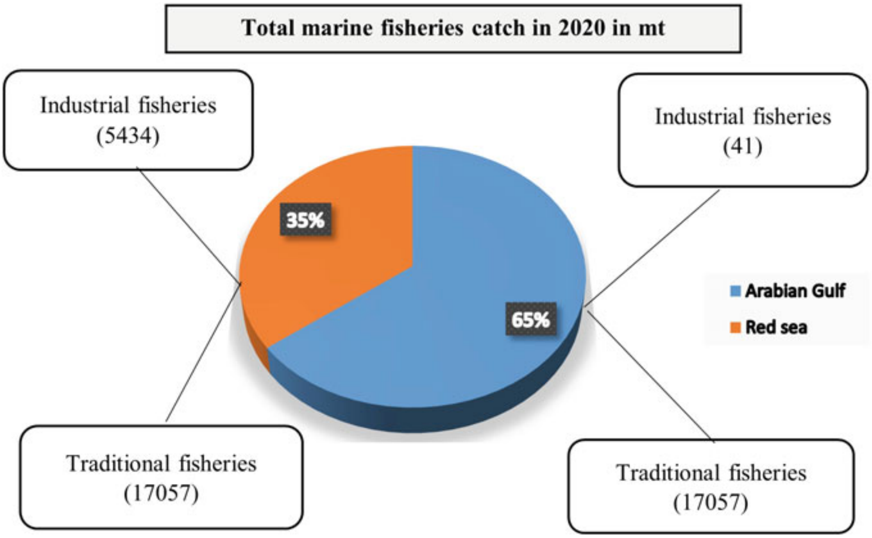

Fig. 4 Total catch from capture fisheries in 2020. *Source* Prepared by the author based on data from General Authority for Statistics (2022)

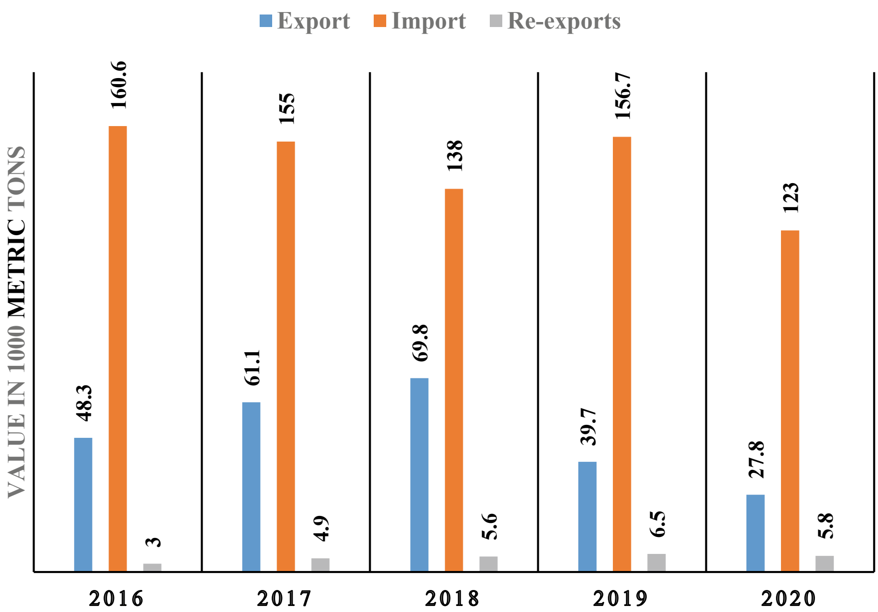

Fig. 5 Total exports, imports and re-exports of fish and shrimps (2020). *Source* Compiled by the authors based on data from General Authority for Statistics (2022)

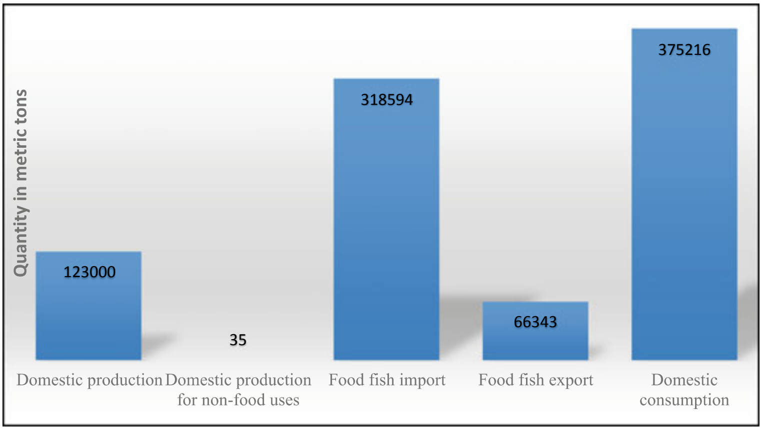

Fig. 6 Saudi Arabian fish and seafood supply and utilization in the year 2018. *Source* Compiled by the authors based on data from FAO (2021)

It is evident from supply and trade data (Fig. 6) that seafood consumption in the country is relatively low (Selvanathan et al. 2015). The estimated annual average consumption per capita is approximately half of the global average (Khan et al. 2017). Seafood consumption in Saudi Arabia decreased marginally between 2014 and 2018, owing to factors such as the ongoing Saudi nationalization policy, the implementation of a value added tax, supply bans on third-country imports (tilapia and pangasius-like species), shrimp-dominated aquaculture production (Papageorgiou 2020).

Several changes in national and international policy have contributed to the rapid growth of Saudi Arabia's population and income (Sultan and Haque 2018). More importantly, dietary patterns are changing, though the traditional pattern of increased protein intake remains dominant (Selvanathan et al. 2015). Traditionally, seafood has been an integral part of Saudi cuisine along the Arabian Gulf and Red Sea coasts, but not in the inland areas. To be more specific, there appears to be a modest increase in consumption of fresh fish in addition to other food items (Khan et al. 2017). 'Frequency of fish consumption in Saudi Arabia 2019' a report published by Statista Research Department (2020), revealed that 30% of Saudi Arabians purchased fish several times per week, with another 27% reporting that they consumed fish at least once per week, 24% once or twice a month, and 13% less frequently. In contrast, only 6% of respondents said they had never purchased any fish. According to an FAO report, the increase in seafood consumption should be balanced by an increase in supply from its long coastline.

Presently the Saudi Arabian population consumes an average of 35.7 g of animal protein per day (Table 2), which is higher than the global average (33.2 g), while its consumption of fish as animal protein (8.2%) is relatively lower than the global average (16.5%). As long as the rising Saudi population, that developing at a rate of 2.9% per year, and the evolving consumption pattern, that are already shaping the market, are combined with a national campaign promoting the seafood consumption,

Table 2 Contribution of fish to animal protein, 2019

Country	Protein per capita intake—2019 (g/capita/day)		
	Fish and seafood	Protein animal based	Share of fish %
World	5.5	33.2	16.5
Asia	6.4	29.1	22
Northern Africa	4.2	24.2	17.3
Southern Asia	2.4	17	13.9
Western Asia	1.8	31.3	5.8
Saudi Arabia and selected neighboring countries			
Egypt	6.5	23.7	27.2
Iran	3.3	25	13
Iraq	1	12.5	8
Israel	6.4	76.4	8.3
Jordan	1.4	25.2	5.6
Kuwait	4.1	49.4	8.3
Lebanon	2.3	25.3	9
Oman	7.3	40.9	17.9
Saudi Arabia	2.9	35.7	8.2
Sudan	0.3	19.9	1.6
Turkey	1.3	39.7	3.3
United Arab Emirates	6.7	35.7	18.7
Yemen	1	11	8.7

Source Compiled by the author based on data from FAO (2021)

the Saudi market is projected to grow at a rate of about 8% per year over the next decades (Khan et al. 2017). Consequently, Saudi Arabia is expected to have an annual seafood demand of approximately 700 thousand mt by 2030. As landings from wild fisheries are expected to decrease and stricter safety protocols are expected to be imposed on fishery imports, which will result in aquaculture becoming Saudi Arabia's main source of seafood (FAO 2020). Moreover, the country's strategic geographical location provides it with the ideal opportunity to become a leading exporter of seafood to the GCC, European, and Asian markets (MEWA 2021).

2.3 Constraints in Seafood Production

There are several limitations associated with aqua farming in Saudi Arabia. Aquaculture development in the region is still hindered by the lack of coastlines with appropriate soil and freshwater access, the inadequate tidal amplitude for the land-based culture, and lack of suitable marine sites (Alharbi et al. 2017; Hozumi et al.

2018). Nature also plays an important role in limiting sustainable aquaculture production. The region's severe climate poses a significant obstacle, limiting the productivity from inland aqua farming systems (Al-Maamary et al., 2017a, b; Memon et al. 2022).

The majority of fish farms spend most of their operating budget on feed, so even a slight change in the cost or conversion of feed will have a significant impact on profitability (Hameed et al. 2022). Although it would be desirable to have abundant locally sourced food ingredients, such goals can only be achieved if they can be produced in adequate amounts and to a comparable quality as imported feed ingredients (Gasco et al. 2018). As a result of the COVID-19 pandemic, it has become apparent that the use of complex supply chains is vulnerable, which should stimulate efforts to substitute locally produced feed ingredients with imported raw materials. Research on protein-rich materials should be prioritized since protein is an important component of the majority of fish feed formulations. There are a number of these foods, including marine worms, seaweeds, insect protein (black soldier or crickets flies, which feed on waste), autotrophic and heterotrophic algae that are used to produce protein and oils (Schizochytrium for omega-3 fatty acids), halophyte plants (Salicornia for omega-3 fatty acids), bacterial and yeast protein, and byproducts from animal and fish processing (Hameed et al. 2022). In order to improve feed processing and feeding efficiency it will always be necessary to review a variety of diet formulations, conduct applied research to evaluate new raw materials, and conduct research on improved feed processing methods and feeding systems (FAO 2019).

The concept of multiple species flexibility in rearing is brand-new to the Saudi Arabia. To reduce the amount of risk associated with mono-species farming systems, the GCC's agricultural strategy should be a combined program involving diverse species. Yellowfin seabream spawns in February off the coasts of Dammam (Eastern Saudi Arabia), Bahrain, Kuwait, and Qatar; Sobaity seabream spawns in March, Grouper spawns in June, and Asian seabass spawns between May and June. Beginning in September, exotic captive European seabream is fertile for reproduction. In a multispecies, flexible fish hatchery, the successional breeding of a multitude of species mitigates the potential losses or mortality of any one fish species (Lam et al. 2012). In addition, hatchery-produced seed closely resembles wild seed genetically. Yet genetic selection can significantly improve the performance of fish. Based on experience with tilapia, approximately ten % growth can be achieved per generation of selection (Elhendy and Alzoom 2008), whereas further qualities, like disease resistance, may also be improved by genetic selection (Maulu et al. 2021). By means of biodiversity is concerned, it may be appropriate to use native strains, however, a well-organized genetic selection program can enhance performance of fish and increase productivity of the farm (Shellem et al. 2021). Furthermore, it will allow captive-bred seeds to be distinguished from natural seed strains, thus raising the demand for captive stocks and preventing wild seed stocks from being overexploited (Blanchard et al. 2017).

Due to the implementation of biosecure practices and the introduction of specific pathogen free (SPF) stocks, management of health issues have been adequately addressed in shrimp farming, however insufficient attention has been paid to other species, such as tilapia, where there are several risks associated with hatchery production and grow out culture (Young et al. 2021). Besides upgrading diagnostic and treatment capabilities for disease outbreaks, a biosecure fish farming system is urgently required as an alternative to flow-throw ponds and cages (Dunne et al. 2021). It is impossible to control the spread of infection if the farm is located nearby and the outlet of one farm serves as the entrance to another farm. Aquafarms must operate zero-discharge systems or RAS systems, such as in-pond raceways, or maintain sufficient distance among production facilities (Dunne et al. 2021; Hozumi et al. 2018). To combat disease, the FAO progressive management pathway approach to aquaculture biosecurity should be widely adopted.

2.4 The Demand—Supply Gap in Fishing

Fish production from the Red Sea fell by 70% in 2013 (Tesfamichael and Rossing 2016). The drop is attributed to several factors such as sewage pollution, coastal erosion, fish migration, global warming, lack of rain, floods (Alharbi et al. 2017; Shellem et al. 2021). According to Ministry of Agriculture statistics, fish stock may decrease drastically from the Red Sea over the next decade. The high per capita income and dynamic lifestyle and diet that invites high-quality food products drive demand for seafood in the Saudi Arabia (ElShehawy et al. 2016). With steady-state population growth, fish demand (Table 3) is expected to reach an all-time high of around 644,886 mt in 2030 (FAO 2021). Overexploitation, rapid consumption growth, and insufficient investment in the farming and fishing sectors have resulted in major reliance on imports. Various production-oriented initiatives have been undertaken by the government to reduce import dependency and meet the country's increasing seafood consumption. As part of its strategy the government is focusing primarily on increasing the efficiency and competitiveness of locally produced food products.

As the aquaculture industry develops in the Kingdom, efforts must be made to prevent it from becoming a profit-making activity for a wealthy minority, but rather to reconcile the use of resources with the economic interests of the fish farmers. Tailor-made ventures could deliver economic benefits to coastal fisher folks through mini-scale coastal fish farming or other related activities, primarily to reduce the use of destructive fishing gear (FAO 2021). There must be an end to the use of destructive gargoor traps as well as the capture of threatened species (such as Najil Grouper and Giant Grouper species). Since the poor are frequently omitted from aquaculture direct involvement because of high investment or the deficiency of access to the important resources, such as water, land, or fish seeds, they could not able to reap the profits that fish farming is theoretically capable of delivering. In order to achieve sustainable coastal aquaculture, intensive training sessions are required for the suburban coastal famished workers, as well as the issuance of appropriate licenses suitable to their primitive farming structure (Khan et al. 2017). Developing this type of fish farming practice for the benefit of every social group and island communities is crucial. A

Table 3 Aquaculture growth potential in Saudi Arabia (2019–2030): a demand-side analysis

Saudi Arabia	Baseline	Forecast to 2030			
		Growth of population		Population growth + higher per capita fish demand	
		2030	2030 compare to baseline	2030	2030 compare to baseline
1. Per capita fish demand (kg/capital/year)	11.34	11.34		16.4	5.06
2. Population (thousand)	34,269	39,322	5054	39,322	5054
3. Total fish demand (mt)	388,448	445,735	57,287	644,886	256,438
4. Fish supply from aquaculture (mt)	75,400	214,229	138,829	214,229	138,829
5. Supply demand gap	na	na	81,542	na	− 117,609

Source Compiled by the authors based on data from FAO (2021)

variety of alternative livelihood options should be provided to coastal fishermen who engage in destructive fishing practices. Fish fattening in pens (Rabbit fish/groupers) is a good and healthy business proposal for the Kingdom (Papageorgiou 2020).

2.5 The International Market Scenario

Presently in the European Union, imported aquaculture products are the subject of considerable debate (Farmery et al. 2020). The increase in imports, primarily from Africa and Asia, has raised concerns about health and environmental standards during the production process, while many European producers have witnessed price declines or the substitution of one product with a cheaper alternative (FAO 2021). In recent years, the continued expansion of production has caused a series of supply shocks that have led to falling prices and the demise of numerous producers. With the increasing consumption of frozen and processed fish products in Europe and the appearance of Asian products (from Recirculatory aquaculture systems—RAS) on the markets like European sea bream, Asian seabass has become an undifferentiated entity product that frequently cannot compete effectively with fish with lower production costs (Issifu et al. 2022). Differentiation will necessitate a more advanced level of processing that enables consumers to identify products and differentiate their quality more effectively (Fiaz et al. 2018). Maintaining competitiveness and market share in countries with greater competition and consumption requires a cost leadership strategy (Blanchard et al. 2017). Penetration strategies are required in low-potential markets, while differentiation can help capture the most affluent consumer segments in the markets with greater consumption in high potential countries (Boyd et al. 2022).

2.6 Investment in Seafood Farming

The aquaculture industry in KSA is a priority for the government. Vision 2030 for the Saudi Arabia includes a plan to produce high-quality food in a sustainable way (MEWA 2021). The MEWA is committed to producing 600 thousand mt of fisheries products by 2030 as part of Vision 2030 and has thus launched a dedicated program to this end. The National Fisheries Development Program (NFDP) aimed at developing Saudi Arabia's fishing industry will attract over $4 billion in foreign and local investment as part of the Kingdom's Vision 2030 scheme for diversifying its economy. Saudi Arabia is well-known for its high-quality and risk-free seafood due to its stringent quality and safety assurance programs. Recent trends indicate that investing in Saudi Arabia's aquaculture will be a highly lucrative endeavor, given the country's domestic and global markets. This consists of investments in infrastructure, R&D, marketing, and the supply chain (NEOM 2021).

Several investment opportunities have been developed to allow investors to start fish farming operations along 15 sites of the Red Sea coastline identified by the ministry as suitable for aquaculture practices based upon thorough explorations of the shores of the Red Sea (MEWA 2021). In accordance with this, these areas strictly adhere to the standards set by the Fisheries Department of the MEWA, Saudi Arabia. Similarly, several opportunities have been identified along the aquaculture value chain and are ready for investors to enter. These opportunities include hatcheries, grow-outs, feed mills, and processing facilities.

In spite of the global economic downturn, the GCC countries, particularly Saudi Arabia, are experiencing sustained economic growth. It is therefore clear that conducting business in Saudi Arabia through a joint venture offers foreign investors a great opportunity, especially in times of a less favorable economic outlook in other regions of the world (FAO 2022). Furthermore, recently government legislation was enacted to enable investors to control a company, while also allowing joint ventures and other types of operations.

2.7 Governmental Policies

It is crucial that government policies expand programs that encourage the farming and consumption of seafood. Poor fisheries policy fuels the high importation of seafood. The government should encourage small, medium, and large businesses to invest in and prioritize local production for the benefit of the local populace. Among the prime objectives of the Kingdom's agricultural development is to achieve and sustain a prudent level of self-sufficiency in food production while balancing the interests of both producers and consumers. This will facilitate the earning of a reasonable income by farmers in agriculture as well as improving rural living standards. Rural residents should profit from seafood farming activities (Young et al. 2021).

With a greater emphasis on fish farming, the government undertook a massive policy shift in the production and marketing of fish products. As part of it, the Saudi megacity development project NEOM has signed an agreement with Tabuk Fish Company for the region's largest fish farm (NEOM 2021). Plans were drawn up for a fish farm with a production capacity of 70 million eggs/annum, making it the largest hatchery in the Middle East and North Africa (MENA) region and a turning point in the aquaculture industry. It is anticipated that this will increase aquaculture production utilizing the most recent technologies, thereby attaining the country's aim of producing 600,000 mt of fishery products by 2030, assigning the country at the lead position in sustainable aquaculture development, and contributing to food security.

A number of initiatives are underway by the Saudi government, including development of technologies and production of fingerlings of native species, establishment of a framework for aquaculture, relaxation of institutional and investment restrictions, and mapping of potential sites for aquaculture (FAO 2020). Along with spending a record USD 3.5 billion on developing aquaculture, the government has also urged foreign investors to invest in the seafood industry (Vision 2030 2020).

Vision 2030 is a framework devised by the Kingdom to diversify into public service sectors such as education, health, recreation, tourism, and infrastructure, in order to reduce reliance on oil. It contains an ambitious and realizable plan for an ambitious nation. Saudi Arabia, which is typically perceived as a religious and conservative nation, intends to bolster its economy with non-oil trade and project a more secular image to the world. Another important aspect of this vision is to reduce the reliance of the country's citizens on subsidies, higher wages, and a greater proportion of the country's investments in the private sector, albeit with more stable and abundant employment opportunities. Accordingly, the fishing industry will benefit from increased private investments, including those from national and international investors.

Several initiatives rolled out as part of Saudi Arabia's Vision 2030, such as the development of economic cities (e.g., Jazan), the Neom megacity, and tourist destinations, as well as the empowerment of women to enter the workforce, are likely to increase consumer retail spending on health products, such as seafood, organic variants of fresh fruits and vegetables, and others. As part of the Saudi Food and Drug Authority's (SFDA) ongoing effort to standardize import quality, some countries that did not meet GCC Standards Organization (GSO) requirements, such as Egypt and Myanmar, were temporarily or permanently banned from supplying seafood such as tilapia, mackerel, and shrimps, results in a shortage of seafood availability (Memon et al. 2022). Consequently, there was an increase in price, caused by the inability to increase speedy production to fill the resulting gap in supply.

3 Implementation of the National Food Strategy—Saudi Arabia's Vision 2030

The food security strategy focuses on initiatives for sustainable agricultural production for the next ten-year by the MEWA and the national transformation program. Fish self-sufficiency is one of the commodities targeted by the strategic plan for sustainable agricultural production. MEWA reported a total fish production of 119,000 mt in 2022, achieving a self-sufficiency rate of 59%. On the demand side, the strategy emphasizes encouraging the population to adopt a healthier, more balanced diet.

In addition to this, the MEWA has launched 5 innovative programs that could help to improve the national output, help the local economy, and ensure food security (MEWA 2021). These programs are part of the National Industry Development and Logistics Program (NIDLP), which was recently launched by His Royal Highness Prince Mohammed bin Salman bin Abdulaziz Al Saud, Crown Prince, Deputy Prime Minister, and Minister of Defence. The first initiative in this regard is the "Marketing Campaign", which is designed to increase public awareness about the health benefits of locally produced fish as compared to imported fish and to encourage per capita fish consumption from 9 to 13 kg. A second initiative, the "Investor Attraction Campaign," is intended to raise the investments in fish farming sector by attracting foreign and domestic investors in order to satisfy fish demand and enhance fish consumption pattern, which will in turn enhance local production, increase exports and reduce imports, and decrease the cost of fish production over time. This initiative is aimed at the development of marine clusters, which entails the construction of fishing landing sites, the construction of floating docks, the establishment of ice factories, gas stations, boat maintenance workshops, the development of integrated logistics services, as well as the creation of attractive tourist attractions. As a fourth initiative, "Building Infrastructure to Support Aquaculture Sector" is intended to create hatcheries, feed mills, and processing plants to produce 600 thousand mt of fish by 2030, thereby supporting the aquaculture industry and creating employment opportunities, attracting foreign investment and reducing imports of aquaculture production inputs. In cooperation with internationally renowned research institutions, the fifth initiative "Research and Development Support" aims to increase the productivity of aquaculture outputs by introducing new species with a high economic impact to the Kingdom, developing feed systems, reducing fish disease risks, and improving fish health; as well as establishing renowned research institutions that offer expertise and training and assist in introducing modern aquaculture technologies. In addition, this initiative also aims to train and qualify young Saudis for the fishery profession, and that the ministry has several strategic plans that contribute to creating employment opportunities for young men and women.

4 Conclusion and Prospects

The vast coastlines of the Arabian gulf and Red Sea and with its immaculate aquatic features and encouraging ecological conditions, is regarded as a highly untapped goldmine for aquaculture and fisheries production. With proper management and sustainable practices, it would be able to provide the domestic and international markets with nutritious seafood of the highest quality. Saudi Arabia's Vision 2030s national fisheries development plan aims to grasp fish production of approximately 600 thousand mt by 2030. Poor management, environmental pollution, intensive overfishing, and many other factors have contributed to the decline of fisheries, yet landings from biologically sustainable stocks have been increasing over the last couple of years. There is no doubt that efficient fisheries management is capable of rebuilding stocks and enhancing catches within the boundaries of ecosystems in a sustainable manner. Hence refining of fisheries management is critical for restoring aquatic environment to a productive and healthy state thus protecting aquatic food supplies in the long term. A successful recovery of overexploited fish stocks could enhance aquatic food output by contributing to nutrition, food security, economic growth and the well-being of coastal people. Consistently, aquaculture aims to establish a solid pillar to support nation's new economic reforms, contribute to the gross domestic product, deliver skilled employment, providing support in addressing the problem of food security in well ecologically sustainable way possible.

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Chapter 9
Animal Health and Food Security in Saudi Arabia

Sara B. Mohammed and Abdelrahman M. A. Elseory

Abstract While the human population keeps growing, our community has a tremendous challenge to provide enough, safe, and wholesome food for everyone, including foods of animal origin. Food security and food safety are closely linked. Unsafe food contributes to a vicious cycle of illness and hunger that mainly affects young children, the elderly and the sick. On the other hand, a secure food supply promotes national economies, trade, tourism and sustainable development. Thus, it is essential to have access to enough quantities of safe and nourishing food to sustain life and advance good health in our communities. Generally, food safety is affected by different factors such as an expanding global population, climate change, and animals diseases. With every meal we consume, we run the risk of contracting a sickness from either microbial or chemical contamination. More than 200 different diseases can be brought on by contaminated foods, which contain dangerous viruses, bacteria, parasites, or chemical substances. Public anxieties over food safety are elevated during outbreaks of any disease in animals used for food production. If any tissues from an infected animal, including meat or milk, are permitted to enter the food chain, they become a potential source of human infection. On the other hand, animal diseases also affect food availability due to animal death. Veterinary Practices, as well as Husbandry Practices, can play critical roles along the food chain (from farm to human consumption) to enhance the safety, availability, and accessibility of food of animal origin. These practices principally contribute to animal health and welfare.

Keywords Animal health · Animal welfare · Food safety · Food security

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1 Introduction

As the human population keeps increasing, our community meets a massive challenge to provide sufficient, safe and healthy food for everyone, including foods of animal and plant origin (Garcia et al. 2020). The Food and Agriculture Organization (FAO) assesses that to feed inhabitants of 9.1 billion people by 2050, total food production must increase by almost 70% (FAO et al. 2021; FAO 2017).

Raised demand for food has numerous negative impacts on our environment, such as soil erosion, environmental degradation and increased pollution. Moreover, natural catastrophes like floods, fires and diseases, particularly transboundary and zoonotic diseases, present a massive threat to food safety and sustainable food production (Andrade et al. 2018; Tilman et al. 2011; Watson et al. 2007; Otte et al. 2004). Therefore, optimising production systems that provide safe, nourishing and sustainable food must be a priority while maintaining natural and environmental resources for the benefit of forthcoming generations (Shariff 2019). To fulfil this task, multidisciplinary teams of experts from different sectors, including animal health and agriculture, must address these challenges (Garcia et al. 2020).

This chapter aims to expand writing on the impact of animal health on food safety and food security, with an emphasis on research done in Saudi Arabia.

In the first place, this chapter illustrates the value of animal-based foods in human nourishment, as well as their contribution to the global food supply. Secondly, it clarifies the fundamental idea of animal health and animal welfare. Thirdly, this chapter thoroughly discusses the direct and indirect effects of animal health and animal welfare on food safety and security and provides examples. Lastly, it briefly illustrates veterinary services contribute to the security and safety of food.

2 Animals and Human Diet

The principal food origin for the world's human population is agriculture, comprising crop production, orchards, livestock production, fisheries, and aquaculture (FAO 2021). Foods of animal origin (animal-based foods) include food items obtained from an animal like meat, milk, egg, fish, shellfish, the derivatives of meat and dairy (sausage, burger, yoghurt and cheese), and honey (Cabrera-Barjas et al. 2022). There are three central production systems in which the world's livestock (approximately 17 billion) occur: open grazing systems, mixed crop-livestock systems, and confined intensive systems. Calculations based on data between 2001 and 2003 suggest that grazing systems provide 2% of milk and 9% of the world's meat; mixed crop-livestock methods supply 88% of milk and 46% of meat; while intensive systems contribute 45% of meat (Thornton and Herrero 2009; Steinfeld et al. 2010).

Animal-based foods contain several vital nutrients in bioavailable forms essential for human growth, development, cognition and health throughout the life cycle. Some micronutrients like vitamin A, iron, zinc, and calcium are inclined to be more bioavailable in foods of animal origin. While others, like vitamin B12, are naturally found only in animal-based foods. These foods supply several micronutrients concurrently, which can be essential in diets short of more than one nutrient. For example, riboflavin and vitamin A are required for iron mobilisation and haemoglobin synthesis; dietary supplements that contain iron alone may not successfully remedy anaemia if other nutrients are insufficient (Smith et al. 2013). Moreover, these foods are specifically important among nutrition-insecure and low-income communities where a modest amount of animal-based foods consumption can lead to more significant nutritional gains than a diet of plant-based foods alone (Eisler et al. 2014).

Generally, meat, milk and eggs are the primary source of nutrients and contribute significantly to the global food supply.

Meat supplied 11% of the world's food energy, 21% of the protein and 29% of the dietary fat. It also was responsible for 32% of lysine and 16% of cystine of the worldwide availability of bioavailable essential amino acids. For other nutrients, meat delivered highly percentage of vitamins B12 (56%), A (24%), B1 and B2 (15% each), B6 (13%) and B5 (10%). Meat contributes poorly to vitamins C and E, fibres and magnesium. Also, it contributes to a significant portion of several elements such as copper (10%), phosphorous (11%), iron (13%), selenium (18%) and zinc (19%). Meat is an inferior contributor to vitamins C and E, fibers and magnesium (Smith et al. 2022; FAO 2022; Pighin et al. 2016; Mottet et al. 2017).

Milk and its derivative supplied 9.1% of the total energy supply, 54.7% of calcium, 28.1% of riboflavin, 26.1% of vitamin B12 and 24.6% of phosphorus. These foods also contributed significantly to several elements, including protein, zinc, fat, vitamin A, cholesterol, magnesium, potassium, and numerous amino acids (Górska-Warsewicz et al. 2019).

Eggs are one of the healthiest foods available, providing a balanced diet that benefits everyone's health, especially children. According to Kuang et al. (2018), a medium-sized cooked egg (50 g) has 78 kilocalories of energy, 6.29 g of protein, 0.56 g of carbohydrate, and 5.3 g of fat. Plenty of vital proteins, lipids, vitamins, and minerals may be found in eggs.

Insufficient consumption of animal-sourced foods leads to a critical deficiency of essential nutrients necessary for humans' physical and mental development, particularly for kiddies. Additionally, the demand for animal-based foods is anticipated to rise in the ensuing decades, with the largest increases anticipated in middle- and low-income nations (Alexandratos and Bruinsma 2012).

Since livestock is the major supplier of foods and vital nutrients, animal health and welfare are the keys to livestock production and productivity. It is well known that livestock needs a minimum level of care to be productive. Thus, improving animal welfare, which is connected intrinsically with farm animal husbandry practices and animal health, will boost the productivity of animals (Skaperda et al. 2019).

3 Animal Health and Animal Welfare

3.1 Animal Welfare

Animal welfare means "the physical and mental state of an animal concerning the conditions in which it lives and dies" (Hewson 2003). There are five pillars of animal welfare, including (a) liberty from starvation and thirst by providing a balanced diet and freshwater; (b) liberty from discomfort by equipping a proper environment such as a resting area and shelter; (c) liberty from pain, injuries and illness, by prevention, diagnosis and remedy; (d) liberty to express normal manners, by supplying adequate space, suited facilities and a group of the animal's kind; (e) liberty from anxiety and distress, by providing conditions and therapy which avoid mental suffering (Mellor 2016).

3.2 Animal Health

Generally, health is clarified as physical and psychological well-being. In the case of animals, health may be explained as the absence of disease or an animal's normal behaviour and functioning compared with other individuals that determine the standard and health (Ducrot et al. 2011). Based on both definitions, animal health is a crucial component of animal welfare. Although the concept of animal health in the literature reviews covers different approaches, it can simply divide into the following approaches; animal diseases, animal welfare, and animal productivity (Gunnarsson 2006).

Several pathogens, including viruses, bacteria and parasites, can cause animal diseases. These diseases were classified based on their transmissible, spreading and impact on society, economy and trade (Mcelwain and Thumbi 2017). Among these diseases, transboundary animal diseases, including zoonotic diseases, significantly impact livestock productivity, particularly in developing countries and can result in restrictions on the global commerce of livestock and livestock products (Cartn-Rojas 2012). Transboundary animal diseases (TADs) refer to those epidemic diseases which are highly contagious with the possibility to distribute rapidly across the world. At the same time, zoonotic diseases are defined as diseases that can transmit from animals to humans (Table 1) (OIE 2021).

In general, these illnesses can endanger the world's food supply by direct mortality of animals or production shortages due to the loss of animal power or reducing the availability of animal products, or, in the case of zoonotic diseases, reducing the supply of food or other animal products through the loss of human productivity (Clemmons et al. 2021).

Food-borne diseases are another category of animal diseases that significantly impact food safety. They are a disease commonly transmitted through ingested food and caused by bacteria, viruses, and parasites (Table 1). Many food-borne diseases

Table 1 A selection of animal diseases that affect the availability and safety of food

Disease	Causative agent	Species affected	Other
African swine fever	African swine fever virus (*Asfivirus*)	Domestic and wild pigs	Transboundary disease
Avian influenza	Avian influenza virus (Influenza A)	Domestic poultry; birds and mammals	Transboundary and Zoonotic disease
Bluetongue	Bluetongue virus (*Orbivirus*)	Domestic and wild ruminants; primarily sheep	Transboundary disease
Classical swine fever	Classical swine fever virus (Pestivirus)	Domestic and wild pigs	Transboundary disease
Contagious bovine pleuropneumonia	*Mycoplasma mycoides s*ubsp. Mycoides	Domestic and wild large ruminants; primarily cattle	Transboundary disease
Foot and mouth disease	Foot and mouth virus (*Aphthovirus*)	Cloven-hooved animals	Transboundary disease
Middle East respiratory syndrome	Coronavirus (*Betacoronavirus*)	Camels	Zoonotic disease
Newcastle disease	Newcastle disease virus (*Avulavirus*)	Primarily domestic chickens; reptiles, birds, and mammals possible	Zoonotic disease
Peste des petits ruminants	Peste des petits ruminants virus (*Morbillivirus*)	Domestic and wild ruminants; primarily goats and sheep	Transboundary disease
Rift Valley fever	Rift Valley fever virus (*Phlebovirus*)	Ruminants	Zoonotic disease
Sheep and goat pox	*Capripoxvirus*	Sheep and goats	Transboundary disease
Swine vesicular disease	Swine vesicular disease virus (*Enterovirus*)	Pigs	Transboundary disease
Vesicular stomatitis	Vesicular stomatitis virus (*Vesiculovirus*)	Horses, cattle and pigs; rarely sheep and goats	Transboundary disease
Salmonellosis	*Salmonella spp.*	Domestic and wild animals, including cattle, sheep, goats and pigs, chickens	Food-borne zoonotic disease
Campylobacteriosis	*Campylobacter spp.*	cattle, sheep, goats, pigs, chickens,	Food-borne zoonotic disease
Escherichia coli (E.coli)	*Escherichia coli*	Domestic and Farm animals including cattle, sheep, goats, pigs, chickens	Food-borne zoonotic disease

(continued)

Table 1 (continued)

Disease	Causative agent	Species affected	Other
Listeriosis	*Listeria monocytogenes*	Ruminants, such as cattle, goats, and sheep	Food-borne zoonotic disease
Brucellosis	*Brucella spp*	Sheep, cattle, and goats	Food-borne zoonotic disease
Norovirus	Norovirus *(Caliciviridae)*	Pigs	Food-borne zoonotic disease
Toxoplasmosis	*Toxoplasma gondii*	Cattle and pigs	Food-borne zoonotic disease

Source Clemmons et al. (2021), Villabruna et al. (2019), Bintsis (2017), Román et al. (2013)

are considered zoonotic diseases. The economic costs associated with these diseases come from the effect on food production, healthcare systems and trade (McLinden et al. 2014).

4 Food Safety and Food Security

4.1 Food Safety

Food safety is defined as the circumstances and procedures that are used in the production, storage, processing, distribution, and preparation of food to confirm that it is safe and suitable for human consumption (Farm-to-fork chain). Access to safe food results in promoting people's health and productivity. However, both developing and developed nations have faced severe health concerns related to food safety in the past ten years (Yemane and Tamene 2022).

Similar to other foods, safety issues of animal-based foods start at the initial production stage and persist till consumption (Fig. 1). Thus, it is necessary to have proper practices (Good Animal Husbandry Practices or Good Veterinary Practices) on every farm where livestock are raised for food (Fung et al. 2018; Attrey 2017).

Good Animal Husbandry practices contain animal welfare, animal feeding, and the control and treatment of animal diseases. These practices have been set to ensure buyers that foods that come from animals fulfil satisfactory levels of quality and safety (FAO 2004).

The food safety practices during food processing and distribution in retail shops aim to address the hazards that might occur to food during this chain. These practices include proper food handling, separating raw and cooked, cleaning and sanitation, the correct temperature for storing, use of safe water and the health status of workers (Tegegne and Phyo 2017; WHO 2006).

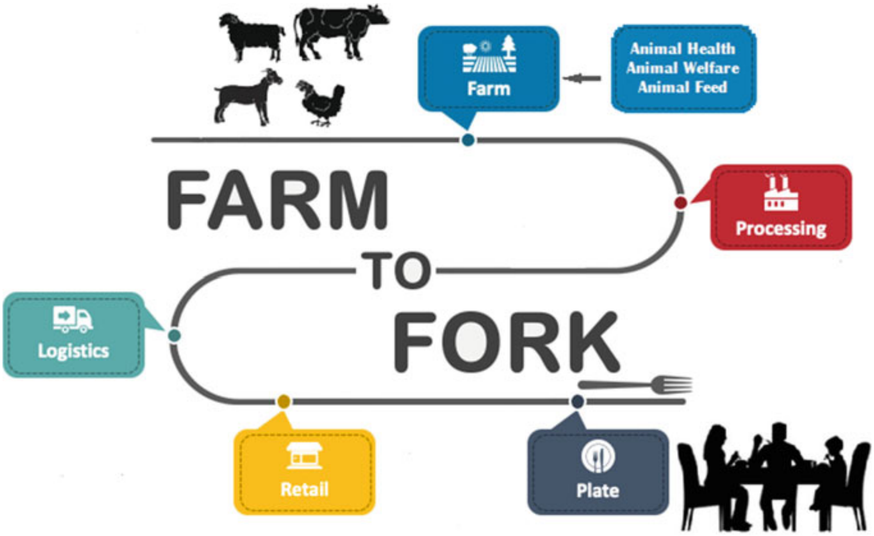

Fig. 1 Farm to fork model for food of animal origin (Modified from: https://www.sketchbubble.com/en/presentation-farm-to-fork.html)

4.2 Food Security

Food security is the availability and access of enough food to all people at any time, allowing them an active and healthy life (Campbell 1991).

Food security is multifaceted and characterized by four pillars: availability, access, utilization, and stability. These pillars are defined as follows:

Availability: means the availability of adequate amounts and appropriate qualities of food, which is provided through regional production or imports.

Access: implies the ability of the individual to acquire sufficient nutritious food.

Utilization: is the capacity of the human body to consume and metabolize food through a good diet, hygienic water, good sanitation and health care to reach a condition of nutritional well-being where all physiological necessities are fulfilled.

Stability: refers to a situation that exists when all populations, households or individuals have access to sufficient food at any time (food secure) and do not risk failing access as a result of economic or climatic crises such as drought (Guiné et al. 2021; FAO 1996).

In general, the safety and security of animal-based foods before harvest are influenced mainly by farm management systems, animal nutritional status, and animal diseases. Whereas after harvest, they are influenced by handling, processing, storage, industrial and commerce practices.

Since animal-based foods are nutritionally dense origins of protein, energy, and diverse vital micronutrients, the shortages in these foods will result in serious health problems (Fig. 2). For instance, the WHO counted that more than 250 million children

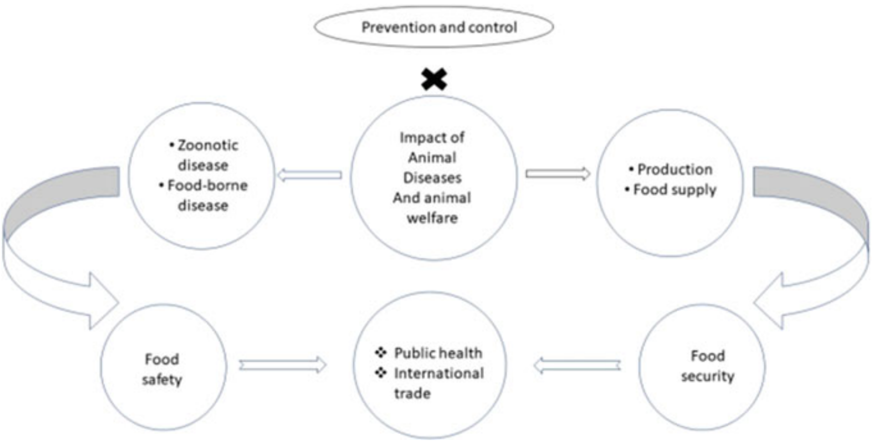

Fig. 2 Diagram shows the general impact of animal diseases and animal welfare in food safety and food security

develop blindness due to vitamin A deficiency (WHO 2009). Furthermore, around 56% of children's deaths in growing nations are due to protein-energy malnutrition, whereas 16.42% suffer from iron deficiency anaemia (Gedfie et al. 2022; Walker 1990). Even small quantities of animal-based foods have been shown to substantially secure dietary sufficiency, prevent malnourishment and have favourable effects on growth, physical activity, mental function and reduced morbidity from illness, especially in children and pregnant women. Besides, eating sufficient amounts of animal-based foods is linked with more capable immune systems and better immune reactions (Smith et al. 2013).

Animal-based foods could also contribute to food security indirectly through income generation. A good example is livestock-production households. Livestock production and marketing are estimated to be necessary for the living of more than one billion poverty-stricken in Asia and Africa (one-seventh of people) (Otte et al. 2012; Staal et al. 2009). Generally, the animal owners consume part of their products and sell the rest, which reflects positively on their income and a healthy household diet.

The assistance of livestock to household revenue varies widely, between 2 to 33% in several developing countries (Staal et al. 2009). For instance, the production and marketing of beef support around 70 million individuals in West Africa, whereas dairy production supports 24 million in East Africa and 124 million individuals in South Asia. The small ruminants aid 28 million in Southern Africa and an extra 81 million individuals in West Africa (Herrero et al. 2013; FAO 2009; Staal et al. 2009).

5 The Impact of Animal Welfare and Animal Health in Food

5.1 Safety and Security

Most people know that food safety and food security are the key elements that sustain the food system to establish a healthy population, and both issues are everyone's business. As the main idea of food security is sufficient, safe and nutritious food for all people, the contribution of food safety emerges here, safe food. Thus, to have healthy, sustainable food production, food safety and food security must come into action together. On the other hand, due to this interrelationship between food safety and food security, any harmful factor can negatively impact food safety and food security simultaneously (Chattu 2015; Hanning et al. 2012).

5.2 Animal Diseases

The World Organization for Animal Health (OIE) lists around 118 notifiable diseases that infect different species of animals (i.e. cattle, sheep, goats, swine, equines and poultry). This list includes diseases that threaten trade in animals and animal products (Mcelwain and Thumbi 2017).

Food deterioration and food-borne diseases are brought on by pathogens that may be found in food, such as bacteria, viruses, and certain parasites. These pathogens are significant issues concerning food safety and security and result in human diseases when consumed through animal products that have been infected with them (Heredia and Garcia 2018). According to reports, approximately 600 million individuals globally get sick after eating tainted food (Guerra et al. 2016).

Although food-borne illnesses are a health concern in both rich and developing nations, the impact of these illnesses is often greater in poorer countries. According to WHO estimation, food-borne diseases are estimated to cause illness to 30% of the population and up to 2 million deaths yearly (Abunna et al. 2016). The majority of food-borne microorganisms have a zoonotic origin, and food items of animal-based are thought to be a major source of food-borne diseases (Ejo et al. 2016).

Zoonotic pathogens can contaminate food in several ways. If an animal is affected by a disease, the tissues of this animal, such as meat or milk, become a source of human infection if allowed to enter the food chain. In addition, many of these pathogens live in the digestive system of healthy animals naturally and can spoil raw meat during slaughtering, milk during milking, or eggs during laying. Cross-contamination can occur of other foods if they come into contact with a contaminated product either directly, during preparation or storage or indirectly via workers, work surfaces, utensils or other objects (Hemalata and Virupakshaiah 2016; Aklilu et al. 2015). Approximately 60% of human illnesses are zoonotic diseases, and around

75% of new emerging human infections are transmitted from animals to people (Bidaisee and Macpherson 2014).

During the last decade, the outbreak of Highly pathogenic avian influenza (HPIA) between 2014 and 2015 was one of the most numerous animal diseases that impacted food security in the USA. Over 42 million egg layers and 7.5 million turkeys were eradicated to control the spread of the disease. Furthermore, the US Department of Agriculture paid around US$ 879 million for detection, reaction and rescue activities. This amount is comparable to 1.82% of the whole poultry production worth in the US (Johnson et al. 2016; Hagerman and Marsh 2016). Although there is no precise data, we can assume that during that time, there was an increase in egg prices which may reflect in the accessibility of this product.

In Africa, HPIA had an adverse effect on pricing for poultry and eggs due to consumer fear and decreased availability of poultry and poultry products as a result of culling and mortality (Birol et al. 2013). In Nigeria, for example, HPAI resulted in 900,000 birds on business farms have died or being slaughtered in 2006, with an evaluated cost of US$ 4.82 million (Mcelwain and Thumbi 2017). The consumer panic and scare in Nigeria led to an extreme decline (around 80%) in poultry meat and egg consumption at restaurants and households (Obayelu 2007). A similar scenario happened in Kenya, as the public panic led to a sharp drop in egg and poultry meat consumption and a loss of revenue for the 65% of countryside farmers who raised poultry (Mcelwain and Thumbi 2017). These are examples of where a food safety concern could lead to food insecurity.

Foot and mouth disease (FMD) is an endemic disease in most of Africa, except a few areas in southern Africa that are deemed free of this disease. Although FMD generally has a short-term impact on an animal's health, the chronic form of the disease can reduce milk yields by 80%, affecting both humans, particularly children, and calves that depend on it (Bayissa et al. 2011). Also, the growth rates of livestock are suppressed due to FMA, and the mortality rate among young animals is typically between 2 and 3% (Rufael et al. 2008).

FMD can result in abortion, which considers a cost as the farmer will have to keep the cows without producing anything for another period.

Reducing milk production, decreasing growth rate and abortion all these effects can reduce the availability and accessibility of animal-source foods. Additionally, FMD can influence food accessibility through quarantine measures, which are applied by most nations in case of FMD outbreak. It is well-known that countries, where FMD are endemic, cannot sell live animals to FMD-free countries (Knight-Jones and Rushton 2013). Even if a country is FMD-free and has commerce with FMD-infected countries, it will experience trade restrictions, which may also affect the trade of vegetables and fruit (Knight-Jones and Rushton 2013).

In 2000, a massive epidemic of Rift Valley fever (RVF) devastated the southern region of Saudi Arabia and neighbouring Yemeni areas. This outbreak was the first ever documented outside of Africa. During this epidemic, approximately 40,000 animals, predominantly sheep and goats, died or were aborted. Whereas 883 cases, with 124 deaths, were confirmed among people in Saudi Arabia. In northeastern

Yemen, 1328 new human cases were reported, including 166 deaths (Al-Afaleq and Hussein 2011).

Analogous to FMD, HPIA and RVF the other transboundary animal diseases, such as rinderpest, classical swine fever and peste des petits ruminants (Table 1), pose a severe risk to the food supply by lessening the availableness of animal products due to restriction of the international trade, which caused a significant socioeconomic and health consequences (OIE 2021). In the 1980s, for example, Africa lost over 2.5 million cattle due to rinderpest (Barrett and Rossiter 1999). In contrast, Rift Valley fever caused more than 100,000 domestic animal deaths in Africa during the 1950s and 1960s (Linthicum et al. 2016). What is more, the economic impact of Rift Valley fever between 2006 and 2007 ranged between 0.01% of the gross domestic product in Tanzania (6.7 million US$) to 5.5% of the gross domestic product in Somalia (471 million US$) (Bron et al. 2021).

Another illustrative example of the impact of animal illnesses on food safety and security is brucellosis, caused by *Brucella* species. Although brucellosis has been eradicated in first world countries, it remains endemic in many African countries. In endemic areas, brucellosis can cause a notable decrease in milk production, weight loss and abortion. All these effects cause harm to food security and the livelihood of farmers who rely on the trade of dairy, meat, and offspring from their animals (Franc et al. 2018). In Mexico, as an illustration, a decrease ranging between 20–30% in milk production has been calculated in brucellosis-affected farmsteads (Herrera et al. 2008). Brucellosis also threatens food safety as the disease can be transmitted from animal to human. Globally, WHO estimated around 393,239 brucellosis cases in humans and 1957 deaths (WHO 2015). Generally, humans get the disease through eating or drinking contaminated animal products (Wainaina et al. 2020). For instance, 62–94% of human brucellosis infections in Turkey are caused by the use of milk products that are contaminated. In contrast, intake of tainted raw milk was to blame for 57% of brucellosis cases in Iran, 69% of cases in Kuwait, and 63% of cases in Oman (Moosazadeh et al. 2016; Buzgan et al. 2010; El-Amin et al. 2001; Mousa et al. 1988).

Similar to Brucellosis, Bovine tuberculosis substantially impacts fertility, milk and meat productivity in cattle, which means a decrease in the availability and accessibility of food. It also affects food safety as a man can get the infection from contaminated milk or meat. Globally, *Mycobacterium bovis*, the causative agent of Bovine tuberculosis (TB), caused 121,268 tuberculosis cases and 10,545 deaths in humans (WHO 2015). According to Hernandez and Baca (1998), tuberculosis was linked to a 4% decrease in milk production. Likewise, Bovine tuberculosis results in declining meat production due to the condemnation of organs and carcasses that are contaminated with TB lesions (Alembrhan and Haylegebriel 2013).

African Animal Trypanosomiasis, caused by the genus *Trypanosoma*, is an example of a parasitic zoonotic disease that has a major impact on food security in Africa. Countries, where the disease is endemic, have persisted to suffer from financial losses of millions of dollars (Mulenga et al. 2021). According to the FAO, this illness causes 3 million cow fatalities annually, and 50 million head of cattle are thought to be in danger of this disease. Loss in cow output alone was evaluated as

US$1.0–1.2 billion annually, which is considered as seriously threatening to food security (FAO 2018).

Food safety is influenced by the variety of microorganisms, including *Listeria monocytogenes*, *Salmonella species*, *Campylobacter*, *E. coli*, and *Toxoplasma gondii,* which are broadly prevalent and pose a considerable hazard to human health in developing societies (Food-borne disease) (Akhtar et al. 2014). Globally, the consumption of unsafe food resulted in 600 million cases of food-borne infections (approximately 7.69% of the world's population) and 420,000 deaths every year (approximately 7.5% of the world population) (WHO 2015).

Although food-borne diseases could happen due to plant-based food consumption, foods manufactured from animal products are considered the primary cause of food-borne illnesses (Table 2) (Heredia and García 2018).

In Saudi Arabia, the major food outbreaks caused by microbial food poisoning and food-borne pathogens have been documented in Mekka during the Hajj and Umrah seasons due to the flourishing of the street food trade during these seasons (Dablool et al. 2014). Bakri et al. (2017) reported that *Salmonella enteritidis* group D, *Staphylococcus aureus*, *Bacillus cereus, Clostridium perfringen*s, and *E. coli* were the most common pathogens in Saudi cities during the previous ten years (Table 3). However, many incidents go unreported because people are less likely to attend health facilities or because food inspection and analysis are incorrect (Alsubaie and Berekaa 2020).

Another report showed that Staphylococci are involved in 41% of bacterial food poisoning cases, and milk and dairy products are the main sources of the infection (Sheikha 2015).

In a study performed in Jeddah, the PCR analysis revealed that both E. coli and Salmonella species were found at higher rates in meat samples from butcher shops. Whereas in small butcher shops, *Salmonella was* found at an incidence of 45% and *E. coli* at 65% (Iyer et al. 2013).

Table 2 Examples of the number of human cases and deaths globally due to food-borne diseases, 2010

Pathogen	Total number of cases (mean)	Total number of death (mean)
Norovirus	124,803,946	34,929
Hepatitis A virus	13,709,836	27,731
Campylobacter spp.	95,613,970	21,374
E. coli	23,797,284	37,077
Shigella spp	51,014,050	15,156
Listeria monocytogenes	14,169	3175
Salmonella spp.	9,311,207	64,541
Toxoplasma gondii	10,280,089	684

Modified from WHO (2015)

Table 3 Outbreaks occurred in Saudi Arabian between 2006 and 2011

Pathogen	Area of outbreak (year)	The morbidity rate
Bacillus cereus and *Clostridium perfringens*	Makkah (2006)	39%
Salmonella spp and *Staphylococcus aureus*	Qassim (2006)	64.5%
Salmonella spp and *Amoeba*	Ahad Rafidah (2009)	77.1%
Escherichia coli	Taif (2006)	60.9%
Salmonella enteritidis	Bisha (2007)	100%
	AI-Hofuf (2009)	56%
	Khaiber (2009)	100%
	Riyadh (2009)	200 cases
	Abha (2011)	26 cases
Salmonella enteritidis group D	Riyadh (2007)	62%
	Najran (2008)	80%
	Al-Ahsa (2010)	33 cases
	Hail (2011)	100%
Salmonella spp	Sulyyel (2010)	64.5%
Staphylococcus aureus	Hail (2011)	39 cases

Modified from Bakri et al. (2017)

Another outbreak was reported in Taif City in 2006 when an extended family registered to the clinic with gastroenteritis signs. This epidemic was attributed to E. coli, which was isolated from raw milk (Al Mazroua and Al Hamadan 2006).

5.3 Animal Welfare

As we mentioned earlier, the main pillars of animal welfare are proper feeding, a suitable environment, treatment and freedom from stress factors such as crowdedness and pain (Mellor 2016). Proper animal welfare correlates to good food safety, in other words, improving animal welfare practices will reflect in the quality and safety of food.

Generally, stress reduces an animal's fitness by impairing its immune system, which can be described as a failure to meet production performance goals or illness and mortality. Consequently, the stress factors in farm animals could harm the quality of food products (Rostagno 2009).

Heat is an example of the stress effect on immunity status. It has been proven that heat stress hurts the immune system through cell-mediated and humoral immune reactions. The release of blood cortisol is triggered by heat stress. Interleukin-4 (IL-4), IL-5, IL-6, IL-12, interferon (IFN), and tumour necrosis factor (TNF) production have all been found to be suppressed by rising blood cortisol levels (Bagath et al.

2019). Immune system deterioration increases an animal's vulnerability to infectious illnesses, which in turn decreases the productivity of animals.

Heat stress often has a negative effect on production and animal well-being. However, fatalities will also happen in extreme or protracted circumstances. One of heat stress's first and most significant effects is reduced feed intake, which lowers growth rates and milk or egg production. Heat stress similarly impacts animal output due to changes in fertility and disease susceptibility (St-Pierre et al. 2003). Heat stress can also affect the quality of animal products, like changing the colour and water-holding ability of both white and red meat, reducing the protein and fat content of milk and decreasing the size of eggs and the thickness of eggshells (Godde et al. 2021).

The welfare of animals during transportation is one of the concerns we must address. Animals must be transported in a means of transport and under conditions that are suitable for that animal, such as sufficient floor area and height, water and feed available if necessary, the animal handler received training, the length of the journey should be minimized, and the convey must not cause any injury (Nielsen et al. 2011). Shipping fever, caused mainly by Mannheimia haemolytica, is a well-known example of transportation's effect on animal health. Shipping fever is a transport-associated disease that occurs in animals several days or weeks after shipment (Maeda and Oikawa 2019). In cattle, the illness is described by severe fibrinous bronchopneumonia, which may lead to death at an early stage. Clinically, cattle often exhibit anorexia, depression, and fever between 40 and 41 degrees Celsius. They may also exhibit a productive cough, an encrusted nose, mucopurulent nasal discharge, shallow breathing, or an expiratory grunt (Gershwin et al. 2015). Based on that, improper transportation could cause significant economic losses to the food supply by reducing the average daily gain and overall performance of animals due to illness.

Animal forages also play an important part in food safety and security. These feeds can be a source of several pathogens for animals that can lead to human illness. These diseases are caused by a proteinaceous infectious pathogen, sometimes known as a "prion." Prion diseases have been observed in a variety of different animals. Different names were given to each of the diseases based on the affected species: Creutzfeldt-Jacob disease (CJD) in humans, Scrapie in sheep, bovine spongiform encephalopathy (BSE) in cattle, and chronic wasting disease (CWD) in cervids. While these diseases appear to have a similar mechanism, they differ in symptoms, pathophysiology, and transmissibility among species (Hedlin et al. 2012).

Bovine Spongiform Encephalopathy is a well-known illustration of the impact of animal feed on food safety. This disease is conveyed to humans by ingesting food contaminated with infected animal tissue (Dealler and Lacey 1991). Cattle get the infection by consumption of forages containing ruminant-derived protein.

What is more, it's necessary to guarantee that the feed for animals is free of any hazardous substances that can harm the animals' health. The poison in the animal feed can occasionally be absorbed by the animal body and then given to the consumer in the form of milk, meat, or eggs.

The safety of our food is also affected by the misuse of veterinary medicines. These substances may leave residues in milk or meat. Thus, some procedures should be followed strictly during animal treatment, such as using suitable therapy for the proper species and at an accurate dose. The medicines records must be kept maintained for each animal to guarantee that any animals or their products shipped to the market have no drug residues or these residues below the allowed limit. The time they demand between administering the last dose of medication and the production of animal-derived products is known as the withdrawal period. This period permits the concentration of drug residue in milk or meat to drop into acceptable levels, which is considered non-threatening to human health (Beyene 2016). Among all animal-based foods, milk is at high risk of drug residues. As an illustration, studies performed in Iran, Pakistan and Bangladesh found that 19.78%, 36.5% and 18% of the milk specimens were polluted with drugs residues, respectively (Rahman et al. 2021; Aalipour et al. 2015; Khaskheli et al. 2008).

6 The Roles of Veterinary Services in Food Safety and Security

The professionals of Animal Health and Welfare are critical in optimising physical health, behavioural health and the animal's welfare. Further, veterinarians and co-workers contribute significantly to preventing, treating and controlling animal diseases at the individual level or even the whole animal population (Carag et al. 2021). Minimising losses due to health problems and improving animal production are among the most essential goals for society. Such improvement necessarily translates into an augmentation of food security and the standards of our lives in all communities across the globe.

Although improvement of animal health can be performed in different ways, prevention and control are the best strategies that can be applied to reach the goal. Biosecurity, farm husbandry, vaccination and treatment are the main pillars to prevent and control animal diseases.

Biosecurity refers to practices that prevent the introduction and spread of disease within a farm (Dargatz et al. 2002), such as isolation of new animals, quarantine procedures, disease testing and treatment if they are sick. By doing these, we prevent introducing a new disease into a group of animals (Barrington 2014).

Good farm husbandry practices can aid in protecting the health of the animals, accordingly decreasing antibiotic usage and the risk of drug residue. These practices include; ensuring a balanced diet, minimising animal stress, and minimising exposure to pathogens. In these ways, we help to build the animal's resistance to disease (Ventura et al. 2021).

Vaccination is a tool for stimulating immunity to specific pathogens and prompting the animal body to produce antibodies or another defence mechanism against infection. Vaccinations not only strengthen a herd's immunity but also recede disease and prevent or decrease the shedding of disease by infected animals (Roth 2011). Knueppel et al. (2010) found that a boost in the vaccination of chicken Newcastle disease leads to a growth in ownership of chickens and egg consumption and also has an effect on decreasing family food insecurity. In another study, Marsh and co-workers reported that a 1% increase in the number of cattle vaccinated against East Coast fever, a tick-borne protozoal disease, is linked with a statistically significant increase (0.08%) in the average reported milk production per herd (Marsh et al. 2016).

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Chapter 10
Role of Smart Agriculture on Food Security in Saudi Arabia

Maha Hadid and Shamseddin Musa Ahmed

Abstract Agriculture is considered "smart" when it contributes to sustainable food security, adaptation, and mitigation. Smart agriculture is defined as a system that uses advanced technology to grow food in a sustainable and clean way by rationalizing the use of natural resources, especially freshwater and soil. Smart farms have the potential to deliver more productive and sustainable agricultural production based on a more resource-efficient approach, especially in the face of climate change and population growth. Among the most prominent technologies used in smart agriculture is the "Internet of Things" (IoT), which connects various devices via the Internet, including mobile phones, home appliances, and machinery used in agricultural factories and fields. The IoT is used for operating, controlling, and receiving data from these devices. One of the most prominent applications of the IoT in smart agriculture is "micro-agriculture", which is the approach used in farm management and crop control through information and communications technology, sensors, remote control systems, and self-operating machines. Artificial intelligence is also a promising technology in agriculture. This chapter aims to clarify the concept, objectives, and pillars of smart agriculture and present some of its successful experiences around the world, with a focus on the Arab region.

Keywords Food security · Technology · Internet of things · Smart agriculture · Sustainability

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1 Introduction

The world's population experiences an alarming rate of increase, from 2.5 billion people in 1950 to 8.0 billion in 2022, which is projected to reach about 10 billion people in the next 18 years (UN 2023). Food production, thus, should keep pace with this persistent increase in population. However, increasing food production is not an easy chore, and remains a real challenge facing agriculture for decades in the wake of, inter alia, limited arable land, water scarcity, climate change, degraded ecosystems, poor investment and economic growth, and unsustainable policies and practices; as yet 350 million peoples remain suffering hunger and malnutrition worldwide in 2023 (WFP 2023). Ultimately, the achievement of sustainable development goals, SDG 2 "Zero hunger" and SDG 3 "Good health and well-being" is questionable by the year 2030, unless real actions have been taken in a sustainable manner.

While agriculture is the pivot sector for triumphing food security, i.e. "all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life, a definition by the World Food Summit in 1996", however, agriculture has a high environmental cost due to its significant emissions, almost third of global anthropogenic greenhouse gases, GHG (Lynch et al. 2021; Menegat et al. 2022). These contradicted food security-environment objectives argue for a large adoption of smart technologies and innovations in agriculture as well as food supply chains (Mesele et al. 2022; Ruzzante et al. 2021), to realize the term "sustainable intensification" that to increase the production with reduced negative environmental impacts on the same land at the time (Aznar-Sánchez et al. 2020). In light of this, the Food and Agriculture Organization of the United Nations (FAO) has published a sourcebook on the concept of climate-smart-agriculture (CSA), aiming at boosting sustainable agricultural yields and financial income generations, enhancing resilience and adaptation to climate change; and reducing and/or avoid emissions of GHG (FAO 2021a). The World Bank (2023) defined CSA comprehensively as "*an integrated approach to managing landscapes—cropland, livestock, forests and fisheries–that address the interlinked challenges of food security and climate change*". Evidently, farmers' food security and livelihood generation were significantly improved coupled with decreased rates of deforestation following the large adoption rates of CSA in rural areas in Tanzania (Nkumulwa and Pauline 2021); also, rice yield has increased by 12% because of the enhanced climate resilience following the adopted CSA strategy (The World Bank 2023).

In response to repeated, periodical challenges and human needs, agriculture has experienced multiple revolutions throughout human history, of which is the green revolution in the mid of the last century which managed to significantly reduce the number of hungry people as well as poverty rates owing to the 36–208% increase in yields of main staples crops (John and Babu 2021; Mehta 2018). Recently, the smart farming/agriculture (SF) revolution has evolved in wake of concerted research for development outcomes (R4D), advanced technologies, innovations, compelling needs, and global partnerships, among others. The intensified use of information communication technology and artificial intelligence remained central in the SF (Bacco et al. 2019; Mohamed et al. 2021); by which agriculture has become a socio-cyber-physical system to assess the impacts evolving from interactions at different micro and macro levels of analysis (e.g. on-farms, sectors, supply chains), among social (e.g. people, business, institutions), cyber (e.g. internet, cloud platforms, digital technologies, and skills), and physical environment and entities (e.g. natural resources, machinery) (Metta et al. 2022). Accordingly, SF could be simply interpreted as "*a technology that relies on its implementation on the use of artificial intelligence (AI) and internet of things (IoT) in cyber-physical farm management*" (Mohamed et al. 2021), *"Smart farming is a farm management concept that may use the Internet of Things (IoT) to overcome the current challenges of food production*" (Navarro et al. 2020), or "*a management concept using modern technology to increase the quantity and quality of agricultural products"* (Pivoto et al. 2018). The keywords in these definitions are management, IoT, and production. In 2017, Ray created a detailed framework for IoT-based agriculture that consists of six layers. The first layer is the physical layer, which includes various devices like microcontrollers and sensors that are used for collecting, exchanging, processing, and transmitting data. The second layer is the network layer which comprises the internet and relevant communication technologies. The third layer is the IoT-based middleware layer, which performs multiple tasks like device management, interoperation, context awareness, platform portability, and security-related tasks. The fourth layer is the service layer, which offers cloud storage and software. The fifth layer is the analytics layer which analyzes big data and predicts outcomes. The sixth and final layer is the user experience layer, which facilitates communication among farmers using social network activities to share and disseminate agricultural knowledge, fertilizer practices, and more. Therefore, this framework can be applied conceptually at different scales and farming systems. For example, introducing seeding machinery in rainfed areas has improved crop establishment and inputs applications, which ultimately increased crop yields by 10–20% compared to conventional methods over much of India (Likhitha et al. 2020). Also, field-based observations stated that the adoption of SF enhanced significantly the water use efficiency in rainfed maize production by 8–66% in Uganda (Zizinga et al. 2022). Because of SF, agricultural greenhouses (a controlled man-made environment/construction for agricultural production, best-suited areas of limited freshwater and fertile land, allowing also off-season year production) have been transformed into minimum-cost production factories of a sustainable food-water-energy nexus as precise amounts of water and fertilizers are applied coupled with controlled pest and diseases (Karanisa et al. 2022; Maraveas 2023; Santiteerakul et al. 2020) a 40% reduction in water consumption was maintained by SF-based greenhouses compared to conventional ones in Qatar (Al-Naemi and Al-Otoom 2023). The comparative study of Maureira et al. (2022) also showed that tomato yield, water footprint, and net income under High-tech greenhouse conditions of 67.7 kg m^{-2}, 34.5 L kg^{-1}, and 40.9$ m^{-2} were better than the open-field based ones of 10.6 kg m^{-2}, 46.6 L kg^{-1}, a 16.1$ m^{-2}, respectively. However, yet the higher energy consumption and GHG emissions remain hotspot research issues on the SF revolution (Maureira et al. 2022).

This chapter will review the following aspects: (a) Addressing the concepts of smart agriculture and the challenges that exist in this framework, (b) Explaining why we need smart agriculture now, (c) Outlining the objectives of smart agriculture, (d) Discussing smart agriculture tools, (e) Highlighting smart farming experiences from around the world.

2 Why Do We Need Smart Agriculture Now?

According to FAO (2021b), the number of people worldwide who are affected by hunger has increased by 161 million in 2020 due to the COVID-19 pandemic, which has impacted an estimated 720–811 million individuals. Moreover, the ongoing Russian-Ukrainian war has further complicated the food supply chain. Recent estimates indicate that the prevalence of undernourishment (PoU) has increased from 8.4% in 2019 to 9.9% in 2020, after remaining relatively stable from 2014 to 2019. Consequently, the sustainable food (SF) revolution is expected to face three urgent challenges in the near future, including sustainably increasing agricultural productivity and incomes while reducing negative environmental impacts, building resilience to climate change, and expanding opportunities for reducing or eliminating greenhouse gas emissions, as well as promoting smart agriculture in developing nations.

Developing countries over much of Africa are the most sensitive countries to climate change and variability as the climate is a central factor to sustainable food security and livelihood generations. Kononen and Arias (2020) confirmed that the Republic of the Congo Democracy (DRC) must support the population to increase their incomes and enhance nutrition for their children, the country needs to develop programs that are capable to achieve these objectives by improving agricultural yields, which have to be sustained in face of persistent climate variability and change through climate and nutrition smart farming technologies and practices. This is why the DRC and the World Bank established a joint long-term National Agriculture Development Program (NADP), a series of projects, expending 1500 million USD over 15 years. The NADP, in its first phase, is expected to provide direct support to about 2,000,000 smallholder farmers to foster their agricultural productivity and market access. The NADP's support to smallholders includes a lot of improved technologies and practices that have been pre-selected based on their "smartness", i.e. being smart means achieving multiple goals in the same location at the same time, particularly being climate and nutrition smart. Those opted options of technologies and practices are offered to smallholders under a tray of smart farming choices, assured through field works and consultations, Examples of these smart technologies and practices are bio-fortified seeds for manioc, production practices for vegetables; also poultry, and eggs are considered nutrition smart as they address a much-needed basic food group as malnutrition is common. Also, early varieties, drought-resilient seeds, and practices such as conservation agriculture and agroforestry are climate-smart as they enhance farmers' resilience, crop yields, and diversified production.

In line with the above several countries like Ethiopia, Ecuador, and Bangladesh, are taking giant steps to align their national development priorities with the sustainable development goals of the United Nations (SDGs). Operationally, the FAO global pilot projects suggested five domains of actions for efficiently implementing smart agriculture: scaling up the evidence base for SF, enabling policy frameworks, strengthening institutions, enlarging investment opportunities, and implementing SF practices at the field level, which could be adopted partially or fully (FAO 2021a).

3 Objectives of Smart Agriculture

Smart agriculture is a sustainable management strategy, that integrates advanced technologies with agricultural work (ISAF 2018):

(a) Persisting agricultural practices to increase production (quantity and quality) in an efficient and environment-friendly manner
(b) Assisting decision-making by collecting, and analyzing datasets, facilitating the selection of best choices
(c) Keeping on-farm variations, e.g. crop yields at a minimum by providing well-tested advanced farming management, enabling farmers to quickly respond to any inter and intra-field variableness in products, meanwhile protecting production resources
(d) Preserving and improving the health and quality of life of farm workers by reducing and/or avoiding the heavy workload along the production phases
(e) Synergizing agriculture with urgent global issues, SDGs, population growth, climate change, and immigration, among others.

4 Selected Components of Smart Agriculture

Most of the farming technologies currently being used or developed can be placed into three categories, which are considered to be the primary pillars of smart agriculture: Autonomous Robotic Labor, Sensors, and IoT (ISAF 2018).

4.1 Autonomous and Robotic Labor

Generally, Autonomous is simply "*work under the control of a computer program and usually use sensors to collect data about their surroundings to navigate*" (Yaghoubi et al. 2013). On the other hand, a robot is a machine that can be programmed and reprogrammed to perform specific tasks. It typically includes a manipulator, such as a mobile body a hand or tool, attached to either a or a stationary platform (ISAF 2018). In particular, the agricultural robot is reported as "a machine designed for farming production use" (Cheng et al. 2023). Recently, ***Autonomous and Robotic Labor*** have taken place across all business entities, and agriculture is not an exception which occupies 40% of the workforce worldwide. As elsewhere, the key goal of ***Autonomous and Robotic Labor*** in agriculture is to reduce its dependency on manual labor and to improve the economic efficiency and quality of the products (Fig. 1). Currently, agricultural robots perform basic functions like fertilization and spraying pesticides. Also, a multifunctional autonomous agricultural robotic machine, i.e. controlled by Bluetooth, could perform many on-farm activities e.g. plowing, seeding, irrigation, and weeding, among others, ultimately allowing the minimum human intervention and the efficient deployment of resources (Sowjanya et al. 2017); this is of much interest to workers in potentially dangerous processes like spraying pesticides for their safety and health (Fig. 2). Cheng et al. (2023) have categorized agricultural robots into three levels: field (i.e. autonomous, decision-making, mechatronic, and mobile operation tools, e.g. tillage and seeding robots), fruit and vegetable (e.g. patrolling, transplanting and picking robots, and animal husbandry robots (e.g. feeding and breeding robots).

The application of robotic technologies will make the future of agriculture brighter. In the absence of robotic and AI technologies, agricultural activities would be time-consuming, laborious, tedious, inefficient, and have poor information on e.g. soil moisture and fertilization conditions, poor monitoring, and low-quality products (Wakchaure et al. 2023). Agricultural robots are totally useful, especially during the pandemic, attested by COVID-19 when a large gap in agricultural workers existed due to massive lockdowns and health restrictions, threatening global food security, and deepening poverty rates. Agricultural robotics is, thus, the most reasonable proliferation of automation technology into biosystems for example greenhouse, forestry, horticulture, etc. Krishna et al. (2017) have designed and implemented IoT-based Android equipped with accurate sensors to appreciate a lot of environmental parameters besides performing various agricultural operations, soil moisture sensing, spraying pesticides, intimidating birds and animals.

4.2 Sensors

A sensor is a device that can detect changes in the source (such as light, heat, pressure, etc.) and capture, process, and translate signals (Dhanarajuid et al. 2022). The results are often a signal that is converted to a human-readable format or transmitted electronically over a network for reading or further processing. Sensors that are installed throughout the smart farm). will collect datasets, including information on weather, light, soil, irrigation, and air quality. The aggregated data will be processed and communicated to the farmer, or directly to the agricultural robots in the field (see Fig. 3). For example, pH is an important factor in soil-water-plant interactions,

Fig. 1 Automation and robotic in smart agriculture. *Source* https://www.vecteezy.com/free-photos. Free stock photos by Vecteezy

which could be easily detected by sensors based on free hydrogen ions. The application of optimum fertilizers is also strongly interlinked with its optimum pH, bearing in mind that fertilizers almost have responsible for a 50% increase in crop yields, following the green revolution (Krasilnikov and Taboada 2022). Other sensors of much interest to smart farming are the soil moisture ones on basis of electromagnetic waves, conductive plates, and among others; each has its pros and cons as some may be less sensitive to salts in the soil while others are sensitive to cracks (entrapped air), temperature; thus, all sensors have to be calibrated before automation or direct use under fields and/or laboratory conditions (Schwamback et al. 2023). Attaining economic production under greenhouses is a controlled environment dependent; thus, climate sensors are commonly used in greenhouses for continuously monitoring their indoor environment e.g. humidity, and temperature (van Mourik et al. 2019). The

Fig. 2 Agricultural drone spraying fertilizers and pesticides on a farm, smart agriculture. *Source* https://www.vecteezy.com/free-photos. Free stock photos by Vecteezy

indoor environment is detrimentally impacted by inappropriate openings of the vents, i.e. to regulate the inside environment; this sensitive opening process has come to be easily and accurately sensed nowadays (Guesbaya et al. 2023). Strong acid solutions have a pH of two, while strong alkaline solutions have a pH of twelve. pH sensing relies on differences in ionization. Natural water with a pH of seven has a very high resistivity, but ionization causes this resistivity to drop sharply. The standard method for sensing acidity is based on the glass electrode system. Wireless Sensor Network (WSN) technology, which is known as the centerpiece of IoT, has been continuously growing in recent years. One of the most significant features of WSN is its ability to identify a network of devices that can communicate and gather information from an observation space through communication links. Since information is transmitted through many nodes with a gateway and connected to other networks like wireless Ethernet, WSNs have been applied in various areas, including forest control, detection of forest fires, smart cities, intelligent training, healthcare, agricultural control, water quality monitoring, military uses, and asset management (Raza et al. 2017).

Wireless sensors allow for the constant monitoring of plants with greater accuracy and, importantly, can detect stages of undesirable states. This is why agriculture now utilizes smart tools and kits, from planting seeds and harvesting crops to storage and transportation. Using a range of sensors to prepare reports makes the entire operation not only efficient, but also cost-effective due to its precise monitoring capabilities. Smart farms currently use various equipment, such as harvesters, autonomous tractors, robotic weeders, drones, and satellites. Sensors can be quickly installed

Fig. 3 Internet of things (Iot) smart industry robot 4.0 agriculture concept, industrial agronomist, farmer using autonomous tractor with self-driving technology, augmented mixed virtual reality to collect, access, analyze soil. *Source* https://www.dreamstime.com/ (free access)

and operated, with the data available online for further analysis almost immediately. Sensor technology is essential for smart farming and precise agriculture as it supports accurate data collection, reducing uncertainty caused by natural variations.

4.3 Internet of Things (IoT)

Agriculture has played a significant role in the development and progress of human civilization. For ages, it has been carried out manually. However, with the world moving towards new technologies and applications, it is crucial to incorporate such advancements into agriculture. In a recent study by Ayaz et al. (2019), it was concluded that the focus should be on smarter, better, and more efficient crop-growing methodologies to meet the increasing demand for food due to the ever-increasing global population and diminishing arable land. As a result, it has become imperative to adopt advanced technologies, such as IoT, to sustainably increase production both quantitatively and qualitatively in agriculture. Xu et al. (2022) defined IoT comprehensively as "*a network in which physical components, such as animals and plants, environmental elements, production tools, and various virtual "objects" in the agricultural system, are connected with the internet through agricultural information* *perception equipment under certain protocols to perform information exchange and communication*". It is the networking and careful fitting of physical equipment with electrical connectivity that can exchange and aggregate data (Fig. 3). The use of software, actuators, and sensors enables a more immediate integration of the physical world into electronically based systems. This integration results in increased efficiency, economic benefits, and reduced human labor. Through sensors embedded throughout each step of the farming process and on every piece of equipment, patterns and trends can be easily identified by analyzing the collected data critically (ISAF 2018). Advances in IoT technology are helping to make water management smarter and optimize consumption in the agricultural industry (Khoa et al. 2019). In farm infrastructure, it is essential to apply IoT technology to enable devices and sensors to proactively interact with farm activities. This feature is the primary characteristic of a 'smart' farming system. Therefore, the primary advantage of agricultural IoT is the integration between hardware and software, as stated by Rejeb et al. (2022). Automated laborers, tractors, and drones are all independent machines equipped with precise cameras, a GPS system, and an IoT connection that facilitates remote monitoring and operation. Innovative technology has resulted in driverless machines programmed by GPS to dispense fertilizers in fields. These machines distribute seeds, covering more land rapidly than is possible manually. Additionally, subsurface drip irrigation methods (SDI) allow farmers to determine the requisite amount of water. Drones used for imaging, planting, and spraying enable farmers to gather more information to monitor crop health, assisting them in optimizing all aspects of their farming, as highlighted by ISAF (2018). The system architecture, however, is a cornerstone in agricultural IoT as several models were developed. Instead of the widely-used "three layers", Xu et al. (2022) defined five basic levels for the system architecture of agricultural IoT, viz. the user level (e.g. agricultural user), application level (e.g. planting), transport level (PAN network: Zigbee), perception level (e.g. sensors), and object level (e.g. crop, livestock).

5 Internet of Things in the World: Success Stories

5.1 Automatic Watering and Irrigation

To maintain agricultural productivity, ensure food security, and boost economic growth in the face of challenges such as climate variability, water scarcity, diminishing labor force, and soil degradation, agriculture needs to innovate. In particular, water is a critical and limited resource in agriculture, and managing it optimally represents a significant challenge (as noted in Ramachandran et al. 2018). To meet this challenge, Mrinmayi et al. (2016) developed a smart irrigation system that can be monitored using an Android application. This system includes two sensors, each with a soil moisture sensor and a temperature measurement, placed near the crop roots. Programmed threshold values for temperature and soil moisture control the supply of water to ensure proper water usage for crops. The system is powered by a regulated power supply.

5.2 Driverless Tractors

The Smart Farm (SF) utilizes information and communication technologies in devices, equipment, and sensors within agricultural production systems to generate a large volume of data and information by gradually introducing automation into the process. SF relies on the transfer of data and a focus on data storage in remote systems to consolidate all farm data and analyze it to make appropriate decisions (Pivoto et al. 2018). Currently, the shortage of manpower is a significant threat to the agriculture sector. However, SF reduces reliance on human labor by automating tasks and enables individuals who are typically excluded from agricultural work, such as women and people with disabilities, to participate. One example of independent technology for farming is a driverless tractor, which operates without human intervention. These tractors are programmed to monitor their positions, change speeds, and navigate around obstacles such as people, stones, animals, or objects in the field. There are many different types of driverless tractors, all of which are entirely independent technologies. They utilize GPS and other wireless technologies to navigate farmland without the need for drivers and can operate under the supervision of a remote control station or alongside a driver-operated tractor. In farming fields, GPS is used for positioning, and coordination between different machines, known as Swarm, is used to complete specific tasks between the Master (Tractor) and Slave (Trolley and Tools).

5.3 Seeding and Planting

Technological development, such as the use of electronic systems and the transfer of data, caused significant changes in the agricultural work environment during the past recent years. These changes require updated information from the producers, marketers, and agents involved in the production to give production decision-making data as well as the strategic and management issues involved. The use of seed-sowing equipment has become popular worldwide. The success of crop production is based on the timely sowing of these crops while reducing the tedious agricultural labor rate. The primary goal of growing seeds with advanced seeding equipment is to achieve accurate seed density and distribution within a given area; Likhitha et al. (2020) implemented a project aimed at establishing an autonomous agricultural system that relies on a microcontroller to assist the execution of on-farm activities e.g. planting seeds and distributing fertilizers at a predetermined distance and depths. The robot-based seeding results were encouraging in terms of sequence and germination of onion. This system was developed for automatic seed cultivation. Herewith the help of the robot, the seeds are distributed in the soil in a suitable sequence, which reduces the seed quantity. Such smart seeding systems will help farmers to carry out agricultural operations efficiently.

6 Smart Agricultures in the Arab World

Smart agriculture, as mentioned previously, refers to the use of advanced farming techniques to enhance production and reduce costs while conserving resources, including the environment. This type of production system is especially critical in areas where water and land resources are scarce, such as much of the Arab region. The Arab region is facing significant environmental challenges, including a lack of arable land, freshwater, climate change, drought, and desertification. These issues have a negative impact on food provision and food security. Climate change is a particularly urgent issue in the predominantly arid countries of the region, which are already vulnerable to frequent droughts and an impending water scarcity. Over the last century, the Arab region has experienced a rise in average temperature due to global warming. The regional climate change study of Shamseddin (2021) stated that because of global warming and increased growing degree days, suitable areas of winter wheat would be decreased significantly by 30% in Egypt and Sudan by the year 2080 under the RCP 8.5 scenario. The consortium report by FAO (2023), warned about the accelerating rate of severe food insecurity in the Arab region, estimated at 54 million people. Shamseddin (2020) stated also that the projected increase in air temperature and evapotranspiration of 3.3 °C and 5%, respectively deprived Sudan of the projected increase in seasonal rainfall of 40 mm, reducing yields of irrigated sorghum and cotton by 29% and 40%, respectively by the year-2070, based on the RCP 8.5 climatic change scenario.

Climate-Smart Agriculture (CSA) is an innovative approach that aims to provide guidance for managing agricultural practices in the context of climate change. Initially introduced in 2009, it has undergone several developments with contributions from various stakeholders involved in its development and implementation (FAO 2018). However, despite its potential benefits, there are challenges to its widespread adoption in the Arab region. These include inadequate communication and internet infrastructure in some Arab countries, a lack of advanced technical skills among many farmers, and the high financial cost of implementing these technologies. Therefore, adopting smart agricultural policies requires a promoting joint action from the Arab world, sharing, exchanging knowledge and ideas and technologies like IoT, communication and information technology which are the basic factors for sustainable agriculture development, enhanced by the well-established regional organizations under the umbrella of the Arab states league like the Arab Organization for Agricultural Development.

It is expected that smart agriculture will be an effective measure in face of climate change and variability as well as a vital and indispensable strategy for raising efficient use of agricultural resources in the Arab countries, ultimately, contributing to achieving food security on the one hand, and the preservation and sustainability of natural resources on the other hand. In addition to its role in providing food that is safe, healthy, and free from chemical fertilizers and pesticides that are harmful to health and the environment. This also pointed to its importance in overcoming the negative effects of climate change on Arab agricultural systems. The importance of smart agriculture in the Arab region is as follows (Hadada 2018):

- Maintained food security.
- Promoted sustainable agriculture by preserving natural resources and raising the efficiency of their use.
- Sustained cost-benefit ratio.
- Introduced newer crops in the region such as cassava and quinoa.

In Egypt, the International Fund for Agricultural Development (IFAD) has adopted a three-pronged approach to promoting CSA (Climate-Smart Agriculture) for smallholder farmers. The approach aims to achieve three core objectives: sustainably increasing yields and incomes, building adaptive capacity and resilience, and mitigating greenhouse gas emissions. Currently, IFAD is undertaking a project that will focus on three governorates in Upper Egypt, where poverty is widespread. The project will primarily focus on rehabilitating old lands, qualifying 50,000 rural families, and increasing income and water-use efficiency for at least half of them. Additionally, the project aims to ensure that 25,000 ha of land are cultivated using climate-resistant water supplies. The project will also provide grants or funding on favorable terms for irrigation equipment, greenhouses, protective belts, protective fencing, and many other climate-smart interventions. Furthermore, it will deploy self-cultivation tools to facilitate sustainability and cost efficiency (IFAD 2019). The Digital and Climate-Smart Agriculture program in Morocco has two core objectives: to increase the use of digital and climate-smart equipment. To monitor and evaluate the program, the World Bank has identified two indicators: adoption rates of climate-smart techniques and practices by farmers, small and medium agri-food companies, and the number of farmers and small and medium agri-food companies adopting digital technologies. The program will focus mainly on building the ecosystem to enable the private sector to manufacture and import digital and smart technologies. The increasing reliance on these technologies will transform the Moroccan agri-food sector and help achieve two strategic objectives: creating jobs in rural areas (especially for youth and women) and managing natural resources in a sustainable and climate-resilient way.

We recall in this regard the experience of the first regional forum for smart agriculture, which was held in Khartoum (Sudan) in 2018, under the slogan "Towards sustainable agricultural development through the Internet of Things and new technological trends"; this forum was the first attempt towards increasing the adoption rate of smart agriculture policies, exchanging experiences on the Arab and African levels in this field, and enhancing the regional and international cooperation in the field of smart agriculture to coordinate efforts and reach sustainable solutions for the future of the agricultural sector.

An example of where smart agriculture is making good progress in the Arab region is the United Arab Emirates (UAE). Despite environmental constraints such as poor soil quality due to the desert climate, limited freshwater resources, and high temperatures, the UAE has made significant efforts over the past few decades to develop its agricultural sector. This has involved policies aimed at reducing the impact of these unfavorable factors and adopting sustainable, climate-smart agricultural methods that focus on maximizing the utilization of cultivated lands and improving the quality of local products to increase their competitiveness. These policies are based on innovative technologies and solutions, such as soil-free agriculture (hydroponics) and organic farming. In addition, the UAE has also strengthened agricultural pest control programs, reduced food waste throughout the supply chain, and increased interest in scientific studies and research in the agricultural field (According to the Ministry of Climate Change and Environment 2020).

6.1 Smart Agricultures in the Kingdom of Saudi Arabia (KSA)

Limited freshwater, hot and dry weather in supplement with frequent dust storms, and desert soil, are the main factors that make agriculture more challenging in KSA. The ever-best way for facing these harsh conditions is smart agriculture. The kingdom has put smart agriculture as a central development policy for transforming agriculture into a sustainable sector, guided by the 2030 vision and the Saudi Green Initiative, SGI: 1. GHG emission reduction up to net zero by the year 2060 based on a circular carbon economy, 2. Afforestation program to plant 10 billion trees, equivalent to restoring and rehabilitating 40 million ha using renewable water resources, and 3. Protecting land and sea biodiversity (Saudi Green Initiative 2023). These strategies, policies and initiatives state the political will to achieve SDGs, including sustainable and fortified food security with zero GHG i.e. smart agriculture. As per FAO (2019), the Kingdom of Saudi Arabia is utilizing various smart agriculture methods, including digital, vertical, and precision agriculture, to attain food security. The expansion of digital technologies in the agriculture and nutrition industry, such as mobile technologies, remote sensing, and computing services, is crucial to boosting productivity and attaining sustainability.

Advancements in technology, sensors, and other wireless devices are being integrated into different daily life agricultural applications in KSA. A digital transformation step taken by MEWA is the establishment of the digital extension platform to provide farmers with areal weather data, advanced research outputs, and guidance, among others through smartphones. Memon et al. (2022) claimed that the strengths of the aquaponics farming system (a system that uses lesser irrigation water than conventional ones) outweigh its weaknesses in KSA. Ammad-uddin et al. (2016) also have confirmed that wireless sensors for Smart Agriculture (SA) are being used for many years, with different challenges like large and remote geographical areas, limited or unavailable communications infrastructure, unaccompanied sensor node accuracy, dunes, and windy conditions. Water resources are precious in KSA. Hence, diligent supervision of water use is required, which calls for a denser sensor network bearing in mind the prevailing dunes and bad weather complications, i.e. Heterogeneous sensor nodes are required (Ammad-uddin et al. 2016). Also, the routing and data gathering scheme need to be redesigned very carefully to opt for all the above factors. The Ministry of Environment, Water, and Agriculture (MEWA) celebrated the occasion of Arab Agriculture Day, under the title (Smart Agriculture: A Better Future for Arab Agriculture). During the ceremony, three prominent farmers in the field of smart agriculture were honored in the cities of Al-Kharj, Al-Ghat, and Al-Qatif. To encourage them to do more work and to motivate the rest of the investors in the field of agriculture to move towards smart agriculture. MEWA took care of the smart agriculture technology, established a project to develop organic agriculture in KSA, also established the Saudi Society for Organic Agriculture and the Organic Agriculture Research Center, as well as prepared and approved the national organic agriculture policy. It also provided great support to farmers and those wishing to switch to organic agriculture. Currently, the Saudi Ministry of Environment, Water, and Agriculture (MEWA) aim at using artificial intelligence technologies in agricultural projects, and it has the plan to activate six projects and link them to artificial intelligence. Artificial intelligence technologies will be used in greenhouses, seasonal fruits, honey production, forecasting and monitoring of agricultural pests and diseases, fodder cultivation, and monitoring places of grain storage, and there is a plan to develop model field schools that adopt IoT technologies and artificial intelligence in agricultural operations such as irrigation and crop fertilization (Aleqtisadiah 2022). As a result of official hard work, the Kingdom of Saudi Arabia won the World Summit Award and ranked first for the Information Society in the year 2023, in the category of digital agriculture and digital electronic services provided through the "Nama" gate after competing with more than 355 projects and over 109 countries around the world (Ministry of Environment, Water, and Agriculture 2022). Precision Agriculture (PA) is a technology that utilizes Global Positioning System (GPS) tools such as satellites, sensors, and information management tools to analyze differences in resource conditions within fields and accurately predict crop production. Recognizing the value of precision farming in the environmental and agricultural sectors, the Kingdom of Saudi Arabia has had many successful experiences in this field. In 2009, King Saud University established the Precision Agriculture Research Chair, which conducted extensive scientific research based on the farmers' partnership system with the goal of transferring precision farming techniques and widely implementing them in the Kingdom. The resulting research, executed in 2011, resulted in a 20% and 30% reduction in the total water used by alfalfa and wheat crops, respectively, while maintaining production (Precision Agriculture Research Chair Bulletin 2015). One of the chair's achievements in the field of precision agriculture between 2009 and 2023 was the publication of over 115 scientific papers, presentation of 47 scientific papers at local and international conferences, and the preparation of five books (Precision Agriculture Research Chair 2023). Vertical farming is another technique that contributes to achieving food security. It involves growing crops on vertically inclined surfaces, such as in a skyscraper or a shipping container, to increase production capacity in the absence of agricultural land. The Estidama Vertical Farming

Program in the Kingdom of Saudi Arabia aims to partner with interested individuals around the world to establish vertical farming units that boost the production of specific crops, such as leafy vegetables and strawberries (Estidamah 2023). At the international workshop on the future of vertical farming in the Kingdom of Saudi Arabia 2021, participants recommended providing investors and farmers with the necessary sources of energy, water, and land for vertical farming. They also emphasized the importance of developing policies and laws to encourage vertical farming and streamlining their approval procedures, building capacities, strengthening the flow of information and knowledge to investors and farmers, and employing agricultural extension in this regard (Ministry of Environment, Water, and Agriculture 2021). One of the most popular methods of vertical farming is hydroponics. According to Memon et al. (2022), the strengths of the aquaponics farming system—which uses less irrigation water than conventional systems—outweigh its weaknesses in KSA.

7 Conclusion and Prospects

Agriculture plays an important role in the economies of countries, especially developing ones, given that increasing production to keep pace with the requirements of society and the regular flow of crops is necessary to achieve economic development, and this increase is necessary to face the population increase in developing countries that are experiencing a population explosion. More productive and resilient agriculture requires a major shift in the way water, soil, nutrients, and other agricultural resources are managed.

The smart approach to agriculture is one of the most important ways adopted by many countries in the world, to find solutions to the problem of climate changes—drought, high temperature, that have led to problems in the quantity and quality of the agricultural sector which has affected the global food situation and the effects of concern for many Among the economies, especially those affected by these negative changes.

As a result of applying smart farming methods and using its tools, it is expected that this smart farming depicts, pesticide and fertilizer use will drop while overall efficiency will rise. IoT technologies will enable better food traceability, which in turn will lead to increased food safety. It will also be beneficial for the environment, through more efficient use of water, or optimization of treatments and inputs.

Therefore, smart farming has a real potential to deliver a more productive and sustainable form of agricultural production, based on a more precise and resource-efficient approach. New farms will finally realize the eternal dream of mankind. It will feed our population, which may explode to 9.8 billion by 2050.

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Chapter 11
Organic Agriculture and Food Security in Saudi Arabia

Samia Osman Yagoub and El Tahir Ahmed Abdelaleem

Abstract The rapid increase in the global population has prompted concerns about how to ensure a safe food supply for the estimated ten billion people by 2050. It is crucial to prioritize access to safe and nutritious food for everyone, particularly those living in rural areas who rely heavily on agriculture for their sustenance, while also preserving the environment. Traditional agriculture alone cannot guarantee sustainable food security. Currently, approximately 12.5% of people in developing countries suffer from malnutrition due to limited access to nourishing food. There are numerous challenges to achieving sustainable food security, but implementing food systems that reduce the use of chemicals and promote the production of safer, higher-quality food can be beneficial. This chapter focuses on organic agriculture and food security in the Kingdom of Saudi Arabia (KSA), demonstrating that organic farming is a sustainable agricultural system gaining popularity over time due to its health and environmental advantages. Additionally, KSA is actively interested in supporting agriculture and organic food products by raising awareness about the benefits and principles of organic farming. By doing so, KSA aims to contribute to the achievement of the nutrition, environmental, and sustainable development goals outlined in Vision 2030, especially those pertaining to sustainable food security.

Keywords Food security · Organic agriculture · Sustainable agriculture · Saudi Arabia

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1 Introduction

The major challenge of the twenty-first century is to guarantee food security under the prevailing condition of climate change and food scarcity. According to United Nations data from 2017, the global population is expected to increase to 8.6 billion by 2030 and is expected to reach 9.8 billion in 2050 (Rahmaniah et al. 2020). This population increase will create a greater demand for food products and feed, which will put immense pressure on agriculture (Boone et al. 2018). However, there are restrictions surrounding natural resources while human requirements continue to grow. Hence, it is crucial to respond directly in order to enhance agriculture as a significant means of generating capital for developing nations. The concept of sustainable food security entails more than just ensuring continuous food production in the long term; it also aims to maintain a balance in producing an adequate amount of food without compromising the earth's ability to provide essential ecosystem services like water cycling and climate regulation (Akhmetshina et al 2018; Sharma and Singhvi 2017). To attain sustainable food security, "it is vital to ensure that everyone has long-term access to nutritious food, to provide sustainable livelihoods to farmers, and to produce food at prices that consumers can afford" (FiBL 2021). Sustainable food security can only be achieved by implementing a flexible and fair food system that incorporates every stage, starting from production and continuing all the way to the ultimate consumer (FiBL 2021).

Based on the importance of organic agriculture on food security. This chapter provides an overview of organic agriculture and food security in Saudi Arabia. It shed light on the historic background, principles and objectives of organic agriculture. Moreover, it gives information on organic practices and certification, organic agriculture in Saudi Arabia and finally the conclusions.

2 Organic Agriculture: Concept, Historical Background and Basics

2.1 Concept of Organic Agriculture

Organic agriculture is all-inclusive and integrated system for managing production that promote and improve the agroecosystem through increasing biodiversity, promoting biological cycles, and improving soil biological activity (Rahmaniah et al. 2020; Sharma and Singhvi 2017; Soni et al. 2022). Organic agriculture focuses on the use of natural inputs, such as minerals and products derived from plants, and does not use synthetic fertilizers or pesticides (Pekala 2020; Rahmaniah et al. 2020). It is also considered as the only solution to conserve land and regenerate soil by using traditional farming methods that are free from chemicals, pesticides, and fertilizers

(Meemken and Qaim 2018; Pekala 2020; Sharma and Singhvi 2017). In typical situations, the expansion of organic farming will cause an increase in the usage of farmland and emissions from agriculture by 2050, when compared to the reference year of 2010. Organic agriculture employs numerous methods similar to other sustainable agricultural approaches, such as intercropping, crop rotation, mulching, and the combination of crops and livestock (Tomar et al. 2023). However, organic agriculture performs well with the utilization of natural inputs (non-synthetic), the enhancement of soil structure, fertility, and the implementation of a crop rotation strategy. It combines tradition, innovation, and science to benefit the collective environment, promote equitable relationships, and enhance the quality of life for all participants (IFOAM 2012). Numerous studies have concluded that organic agriculture significantly enhances farmers' food security and improves their livelihoods (Gupta et al. 2021; IFAD, 2003, 2005; Kleemann, 2011; Parrott et al., 2006; Mariappan and Zhou, 2019; Tomar et al., 2023).

Nowadays, organic agriculture is widely spread to cover at least 172 countries in the world (Meemken et al 2017) with the bulk of organic farmers from developing countries. Specifically, 40% live in Asia, 27% in Africa, and 17% in Latin America (FILBS and IFOAM 2018). Some researchers have argued that organic farming involves low costs, less risk, higher product prices, enhanced social competence, empowerment of farmers and women with low incomes, and those who lack access to credit, provides a sustainable source of income, improves household and farmers' livelihoods and health, and helps enhance the quantity and quality of natural resources (Das et al. 2020; Kleemann 2011; Rahmaniah et al. 2020; Reganold and Wachter 2016; Tomar et al. 2023). Furthermore, organic farming positively affects the occupational health offarmers by decreasing their contact with agricultural chemicals (Das et al. 2020). Nevertheless, adopting organic agriculture is only beneficial when accompanied by transformative approaches to advance environmental sustainability in various sectors. These approaches may include altering consumption patterns, implementing improved production practices, and reducing food waste (Basent et al. 2023).

2.2 *Historical Background of Organic Agriculture*

In the 1920s, the concept of organic farming first appeared and has since remained a topic of global debate. The International Federation of Organic Agriculture Movements (IFOAM) gave the initial definition of 'organic' in 1972. Currently, there are only two main regulators for organic agriculture worldwide, namely IFOAM and the United States Department of Agriculture (USDA). USDA created the National Organic Program (NOP) in 2000 and it sets the national criteria for organically produced agricultural products, excluding food safety and nutrition (USDA 2017). The major principles of organic farming are health, care, ecology, and equality (IFOAM 2005a). The benefits of organic farming include being environmentally friendly, sustainable, producing nutritious and healthy food, and providing revenue and employment opportunities.

2.3 The Principles of Organic Farming

According to IFOAM (2005b), there are four main principles of organic production these are: (a) Health: this recognizes the health of the ecosystem and its components, including plants, humans, soil, and the sphere as a whole, are interconnected and inseparable. Organic agriculture aims to sustain and improve the health of all of these elements, producing nutritious food that promotes wellbeing and health. (b) Ecology is a concept that asserts that organic agriculture ought to be based on living ecological systems and processes. This means working with these systems, sustaining them, and striving to replicate them. (c) Fairness: this principle seeks to establish equitable relationships among all parties of the organic farming process—from farmers and workers to processors, distributors, traders, and consumers—based on shared environmental and livelihood opportunities. Finally, (d) Care: this principle prioritizes the responsibility and cautious management practices and technological choices in organic agriculture to ensure the safeguard of environmental and human health now and in the future (IFOAM 2005b).

3 Organic Agriculture: Objectives, Design, Practices and Certification

3.1 The Objectives of Organic Agriculture

Organic agriculture is another face of sustainable agriculture, the main objective of sustainable agriculture are environmental health, economic profitability, and social justice (Rahmaniah et al. 2020). The key objective of organic agriculture is to maximize the health and yield of mutually dependent societies consisting of soil, plants, animals, and society. This will be accomplished by promoting the right procedure of for soil usage, water, and air, and reducing all types of contamination that might arise from the practical applications of agricultural. Furthermore, it will encourage diligent processing techniques for agricultural products to preserve the organic reliability and essential qualities of the product throughout entire phases (De Cock et al. 2016; Rahmaniah et al. 2020; Soni et al. 2022).

3.2 How to Design Organic Agricultural System

Organic farming refers to the cultivation of plants without the use of harmful artificial additives such as fertilizers, pesticides, antibiotics, and other chemicals. Its primary objective is to achieve sustainable agriculture, as stated by Soni et al. (2022). Multiple researchers in their studies have analyzed the factors that impact farmers' choices to transition from traditional farming methods to organic farming in both developing and developed countries. One critical factor is the availability of government subsidies for organic farming. However, the government may also put policy risk, reducing adoption under certain conditions, (FiBL 2021). Additionally, organic farming could encounter increased production risks due to the prohibition of specific inputs that aid in risk reduction, as stated by Tomar et al. (2023). For instance, chemical pesticides that are helpful in decreasing pest damage cannot be used in organic farming. In contrast, organic farmers use crop rotations, cover crops, and compost to enhance and improve soil fertility instead of depending on artificial fertilizers. Additionally, instead of using synthetic pesticides, they use biological, cultural, and physical methods to control pest growth and encourage beneficial insect populations. In organic agriculture, genetically modified organisms (GMOs), such as herbicide resistant seeds and plants, as well as product ingredients like GM lecithin, are not allowed due to being considered artificial inputs and potentially having unknown risks (Tomar et al. 2023). According to the Codex Alimentarius Guidelines for Organic Food Production, organic farming aims to enhance biodiversity within the system, promote the activity of microorganisms in the soil, sustain soil fertility over the long term, and reduce the reliance on non-renewable resources by recycling plant and animal waste and reintroducing nutrients to the soil. The length of the transition period depends on the site specific factors such as the land's previous use and the specific crops and livestock to be raised (FiBL 2021).

3.3 Organic Practices and Certification

Organic farmers utilize modern farming techniques, including modified crop varieties, methods for conserving soil and water, as well as modern advancements in animal feeding and handling (Tomar et al. 2023). It is important to note that organic farming systems differ from completely closed cycle systems in that they necessitate organic certification. The first step to producing organic crops is transitioning to certified organic production, which involves contacting a certification agency and joining a local organic certification. In order for a crop to be considered organic, it must be grown on land that has not been treated with synthetic chemicals such as fertilizers, insecticides, pesticides, herbicides, and fungicides. for a period of more than four to five years. Nowadays, during the transition to organic certification, records must be kept of all substances used on the land. An inspector will visit the land during this time (FiBL 2021). The production of certified organic agricultural products increases farmers income, and in turned improves farmer's access to food. However, linking organic farmers into certified markets, especially in large cities, requires the adoption of products differentiation through verifiable quality labels. In this context, it is worth noting that, organic farmers have established internal control and auditing systems that are recognized through organic labeling (FiBL 2021). Many farmers in the world have applied organic practices, yet are not certified. In fact, most of the certification principles initiated in developed countries are inappropriate for other regions, particularly in least developing states.

The high demand for organic products in Europe and North America has led to the importation of organic foods from major agricultural corporations in less-developed countries. Many studies have investigated the disparities in yields between organic and conventional systems (Reganold and Watcher 2016). Organic farming is more financially feasible for small-scale agricultural producers than conventional farming techniques, thus encouraging small-scale producers' to intrude the field of organic farming is considered among the best strategies for overcoming several socio-economic difficulties. However, one disadvantage of organic agriculture is that it produces lower and riskier yields. This is a concern when trying to feed a growing population without expanding agricultural land. Furthermore, despite having lower productivity, organic farms generate significantly higher profits (ranging from 22 to 35%) compared to conventional farms. This is primarily due to the higher prices of organic products. Organic agriculture is also more profitable for farmers. The cost of organic farming is 10–40% higher than agricultural crops grown in conventional farms due to factors such as the high cost of obtaining organic certification and the need for manual labor.

4 Organic Agriculture and Food Security

At the World Food Summit in 1996, the definition of food security was established as the condition in which all individuals have ongoing physical and economic access to sufficient amounts of nutritious and safe food to maintain a healthy and active lifestyle (FAO 2015). Food security is multifaceted and involves elements such as availability, access, utilization, and stability (IFAD 2003). Organic agriculture focuses on three primary areas of interest, namely social, economic, and environmental, all of which contribute significantly to improving food security. Due to the global population reaching seven billion people, there is substantial controversy over whether or not organic agriculture can provide sufficient food for humankind. Notably, prominent biotechnology firms, particularly those who gain from using pesticides and genetically modified seeds, question the capability of organic farming to provide sustainable food to the globe. However, organic agriculture can improve yield in specific conditions where farmers face a risk of food shortage. Additionally, organic agriculture can augment income (Jouzi et al. 2017) through the provision of higher financial value and the reduction of input expenses. It can also improve soil productivity, nutrition content, and protect the environment, ultimately improving the socio-economic condition (Bawden 2014; Morshedi et al. 2017). Moreover, even though organic agriculture's output is lower than conventional agriculture, it proves added lucrative to agricultural firms, as consumers are ready to pay more for naturally grown produce (Morshedi et al. 2017).

Governments around the globe are called to support and implement proper policy, including the application of local source organic products, to improve consumer's knowledge on organic farming nutritive value and consequently improve its contribution in achieving food security. In addition, it is requested that donors and significant developmental organizations, specifically the "Food and Agriculture Organization of the United Nations (FAO) the United Nations Conference on Trade and Development (UNCTAD), and the International Fund for Agricultural Development (IFAD)" should provide support and assistance in expediting the adoption of organic agriculture and other agro-ecological systems. These measures are crucial to ensure access to nutritious food for everyone in the twenty-first century (UNCTAD and UNEP 2008). Lastly, we urge research and extension institutions to prioritize their efforts in the field of agroecology and organic agriculture. It is essential to develop long-term solutions that promote and share successful techniques among farmers and technicians.

Organic farming focuses on utilizing resources that are readily accessible in the local area, resulting in reduced production costs. However, it is often regarded as an expensive approach that heavily relies on labor. To solve this problem, one possible solution is to include family members of small-scale farmers in subsistence or small-hold farms. This approach not only helps reduce poverty but also generates job opportunities in developing countries, specifically for smallholders and farmers with limited resources. Organic farming presents the opportunity to increase sustainable income, enhance livelihoods, and improve access to education and healthcare facilities (Kleemann 2011; Jouzi et al. 2017).

When compared to conventional agriculture, organic agriculture exhibits yield gaps and yield stability in terms of temporal variability and production reliability concerning food security. The evidence obviously revealed lower average yields are usually obtained in organic agriculture (Meemken and Qaim 2018). Nevertheless, some scholars highlight the gains of organic agriculture for food schemes and have shown that productivity gaps can be narrowed (Fess and Benedito 2018; Meemken and Qaim 2018; Sanders 2022). In the same line, Fess and Benedito (2018) and Muller et al. (2017) argued that the productivity gap can be shut in the long run by bearing in mind the compositional effects of large areas adjacent to organic agriculture, enhancing agro-ecological surroundings and modifies feeding behavior.

5 Organic Agriculture in Saudi Arabia

5.1 Position of Organic Agriculture in Saudi Arabia

Saudi Arabia is the largest sovereign state in Western Asia, covering an area of 2.15 million km^2 (World Bank 2015) and holding the largest position in the Gulf region. Due to limited water resources and the negative impact of climate change in arid regions, sustainable farming methods are necessary to be adopted. Saudi Arabia's Vision 2030 aims to reduce the Kingdom dependency on oil and diversify their economy by allocating significant funds towards improving the country's food production and processing abilities. The agricultural sector in Saudi Arabia has undergone significant changes since the 1970s with the implementation of government programs promoting modern farming methods. In order to guarantee sustainable agriculture and food security in Saudi Arabia. Fiaz and colleagues (2018) identified four potential categories for dynamic implementation in agricultural extension. These categories are "informal education, technology transfer, advisory services, and facilitation extension". In 2016, the government of Saudi Arabia announced the Vision 2030 initiative, which aims to strengthen the organic sector by investing 200 million USD to increase organic production by 300% (Government of Kingdom of Saudi Arabia 2018). The objectives of this vision include overcoming legal and institutional constraints for establishing organic research centers, promoting cooperation among actors in the agricultural value chain, developing partnerships with other actors, and implementing standards for good agricultural practices. These efforts are meant to provide safe food and support highly profitable farming as an essential resource for the national economy.

After the Ministry of Environment, Water, and Agriculture of the Kingdom of Saudi Arabia announced the national transformation plan, there has been a growing interest in organic agriculture. The goal of this plan is to promote and encourage organic practices among farmers with the aim of achieving a balance between agricultural production and the conservation of natural resources in Saudi Arabia. From 2005 to 2015, due to mismanagement arising from the traditional management practices, organic farming was deemed to be ineffective. Organic agriculture only contributes less than 5% to the overall agricultural production in Saudi Arabia, mainly due to the limited number of certified farmers. Additionally, there has been a decline in the participation of farmers in activities related to organic agriculture and limited collaboration with other stakeholders. Moreover, the focus has primarily been on organic production practices rather than the certification process during this time period (Hartmann et al. 2012; Alotaibi et al. 2019). However, there has been an increase in the area allocated to organic agriculture since 2020. In 2020, the area dedicated to organic agriculture reached 27,000 ha, marking a 2000-hectare increase from 2019. In contrast, the production of organic agriculture in Saudi Arabia reached 99,000 tons in 2020, which demonstrates a 60% increase compared to 2019.

5.2 Saudi Organic Farming Associations

Saudi Arabia has made progress in improving the efficiency of food production, resulting in enhanced food security despite the challenges posed by climate change and limited water resources. In 2005, GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit) was tasked with promoting and developing organic agriculture in Saudi Arabia. This initiative has contributed to the growth of the organic farming sector, leading to the establishment of the Department of Organic Agriculture (DOA) in collaboration with GIZ in 2008. During this time, a comprehensive National Organic Regulation was developed for Saudi Arabia, taking inspiration from relevant European Union legislation, and was officially adopted in 2008. The DOA, as the authority responsible for overseeing the entire organic sector, is tasked with monitoring and supervising the implementation of the initial Saudi Arabian national organic regulation and standards.

In 2014, Saudi Arabia implemented an organic agriculture law for the first time. This law was further supplemented in 2015 by an organic agriculture by-law, replacing the previous regulations and standards. In 2011, the first organic farms were certified in accordance with these new laws. Prior to 2010, local organic operators were certified according to the standards of the European Organic Regulation. However, after the Saudi Organic Standards were recognized in late 2010 and the introduction of a Saudi National Organic Logo in early 2011, operators were certified for the first time according to the new Saudi organic standards in the same year. Additionally, as part of the national market development program, GIZ and FIBL are working on developing value chains and improving the integration of Saudi organic producers with the retail sector (FiBL 2021).

In collaboration with international partners, the Saudi Arabian government and private sector stakeholders, GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit) has developed a national Organic Agricultural Policy for Saudi Arabia. This policy was presented in Riyadh on October 9, 2012 (Bartels and Prinz 2016). Alongside goals for increasing productivity and producing healthy food products, the agricultural policy also takes into account objectives for conserving resources. Additionally, potential support measures were presented (Bartels and Prinz 2016).

The KSA has taken significant steps towards developing the agricultural productivity and enhancing food security under the prevailing climate change and scarce water resources. In recent years, the Saudi government has begun to back the adoption of environmentally sustainable methods. The Saudi Organic Farming Association (SOFA), a private and non-profit organization, was founded in 2007 and has become the most important platform for organic agriculture in Saudi Arabia. The main principle of organic agriculture is to cultivate fresh, tasty, and healthy foods using environmentally friendly techniques, while also maintaining the balance of the farm ecosystem and protecting biodiversity. Although awareness and knowledge about organic farming in the Kingdom are not widely spread, it has been steadily increasing over the years. Any farmer who wants to engage in organic agriculture must acquire a certificate from accredited organizations licensed by MEWA (Alotaibi 2020).

5.3 Organic Agricultural and Livestock in Saudi Arabia

By mid-2015, over 120 organic farms in Saudi Arabia had received certification. Additionally, new farmers are continuously transitioning their production systems to organic farming. These farms are spread throughout the country, encompassing major agricultural production regions like Qassim, Kharj, Al-Jouf, and the Eastern Provinces. Specifically, organic producers are prevalent in Jeddah, Riyadh, and Dammam where the demand is highest (Bartels and Prinz 2016).

Organic agriculture is currently encountering various challenges. These challenges encompass a limited awareness among consumers regarding organic products, ineffective marketing strategies, inadequate extension services, insufficient availability of organic inputs, and a scarcity of well-trained specialists and professionals in the field of organic farming. These challenges have been highlighted in various studies conducted by Willer and Lenoud in (2013, 2019), as well as by Alotaibi in 2020. It is worth noting that organic extension services in Saudi Arabia are not widely available throughout the entire Kingdom, as mentioned in a study by Fiaz et al. (2018). Additionally, organic animal husbandry is not significantly important when compared to organic crop production. In 2012, only around 2.8 thousand farm animals were raised according to organic standards, primarily consisting of sheep and goats. Moreover, there are currently about 735 small ruminants that are in the process of becoming certified as organic, referred to as being under conversion.

Moreover, the numbers of cows raised under organic agriculture is 600 heads in Saudi Arabia in 2021. As for the organic hives, the number of hives reached 6.5 Thousand. In terms of organic agricultural crop cultivation, statistics show that the total area of organic agriculture in Saudi Arabia is 27 thousand hectares for 2021 (Table 1), representing a 1.8% increase over 2020. Fruit (except dates) came first in area with 13.24 thousand hectares, represented by 48.9% of Saudi Arabia's agricultural organic area for 2021, followed by palm tree at 23.8%. The total production of organic agricultural crops in Saudi Arabia reached 98 thousand tons for 2021, the fruit (except dates) accounted for 63.3% of organic agriculture production.

Table 1 Cultivation and production of organic agriculture in Saudi Arabia during 2016–2021

	2016	2017	2018	2019	2020	2021
Organic cultivation area for agricultural crops (Ha)	16.22	16.98	18.64	24.52	26.61	27.11
Production of organic agricultural crops (Ton)	56.26	52.84	44.63	61.44	98.56	98.78

Source Ministry of Environment, Water and Agriculture, Kingdom of Saudi Arabia, Statistical Book, 1442–1443 (2021)

In the Kingdom of Saudi Arabia, we have observed a substantial rise in the availability of organic products from different organic farms across the country, including regions like Riyadh, Qassim, Jazan, and others. There has also been a noticeable increase in animal production, indicating a growing interest in organic products between 2016 and 2021. This information is highlighted in Table 2. Additionally, the efforts made in the field of plant production have resulted in high yields of palm trees, vegetables, and forage, as depicted in Table 3.

Table 2 Total number of organic and transformed, cows, goats, camel/head and beehives/number during 2015–2021

	2015	2016	2017	2018	2019	2020	2021
Cows	278	100	267	281	419	564	600
Goat	5.817	7.449	16.074	15.036	6.432	2.880	3.100
Camel	3	4	352	350	25	57	50
Birds	2.033	1.300	500	1.489	1.504	11.360	12.000
Beehives	1.172	2.363	1.517	1.583	5.794	6.003	6.500

Source Ministry of Environment, Water and Agriculture Kingdom of Saudi Arabia, Statistical Book, 1442–1443 (2021)

Table 3 Total production of palm trees, vegetables and forage organic and conservation (tons) during 2018–2021

Palm trees	2018	2019	2020	2021
Total production	12.206.0	13.616.39	16.591.52	16.666.89
Organic production	1.168.8	1.091.83	1.495.35	1.644.88
Under conservation	2.489.0	2.776.37	4.818.21	4.818.21
Vegetables				
Total production	5.517.71	6.605.58	7.099.09	7.129.000
Organic production	386.09	94.45	139.17	179.51
Under conservation	306.20	344.14	480.49	480.49
Forage				
Total production	4.311.70	3.218.90	10.600.40	10.630.00
Organic production	440.11	469.80	84.72	114.70
Under conservation	289.4	110.45	276.40	276.40

Source Ministry of Environment, Water and Agriculture Kingdom of Saudi Arabia, Statistical Book, 2021–2022

5.4 Saudi Arabia's Organic Farming Market

In Saudi Arabia, consumers are increasingly showing interest in "safe" food. However, without a sustainable market, the supply and demand for such food will remain underdeveloped. It is crucial for the government to establish the Saudi National Organic logo and create the necessary regulatory infrastructure to support the organic agriculture sector. This will enable effective regulation of organic production and foster consumer confidence. A stable market is essential for consistently meeting the demand for organic products. The organic farming market in Saudi Arabia has exhibited promising growth in previous years up until 2019, and this growth is expected to continue in the forecast years from 2021 to 2026.

6 Conclusion and Prospects

The increasing local and global demand for organic products affirms that Saudi Arabia has a promising future in organic food production. The Saudi government provides support to farmers who implement organic farming practices, offering incentives such as subsidies and technical assistance. However, organic farming also faces numerous challenges that need to be addressed for the growth and prosperity of the sector. One challenge, for instance, lies in the limited support for scientific research focused on adopting and improving organic farming techniques to adapt to Saudi Arabia's natural conditions and climate changes. These obstacles can be overcome by establishing cooperative societies for organic farming and implementing certification systems for organic products. These measures would ensure the production of safe and healthy food, while maintaining a sustainable environment. By creating sustainable food systems, we can safeguard the rights of future generations.

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Chapter 12
Applications of Solar Energy for Enhancing Sustainable Food

Mohamed A. Eltawil, Mostafa M. Azam, and Maged Mohammed

Abstract The population is increasing worldwide and is expected to surpass 9 billion individuals by 2050, and at the same time, the global demand for food will increase dramatically and this will affect food security, which will negatively affect sustainable development. Recent developments in urbanization and Agricultural industrialization exerted pressure on agriculture, which played a crucial role in meeting the worldwide food demand. Adapting new and efficient methods for the sustainable agri-food sector is more crucial. The supply chain of agri-food mostly depends on fossil fuels which contribute to global warming and greenhouse gas emissions (GHGE). Several scenarios or strategies have been applied to minimize the GHGE by replacing renewable energy sources instead of fossil fuels. The utilization of solar energy technology is presently growing and has the potential to be incorporated into various agricultural industrialization activities. This has the ability to provide an alternative and sustainable solution in comparison to current practices. The aim of using solar energy advancements in the sustainable food industry is to help both society and agricultural communities in different areas and sizes improve their productivity and sustainability. This chapter addresses typical problems by introducing recent solar energy technologies that are utilized in drying systems, greenhouse cultivation, solar heating and solar refrigeration. The purpose of this chapter is to act as a guide

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for scientists, engineers, and stakeholders who are dedicated to sustainability and are involved in projects concerning food security, energy, and climate change. Applying solar-based agriculture projects in Saudi Arabia, outlining the key challenges and benefits, and presenting them will bridge the gap in knowledge between producers and researchers in the field.

Keywords Sustainability · Fruits and vegetables · Greenhouse · Solar drying · Solar cooling · Photovoltaic

1 Introduction

It is important to monitor and decrease food waste during all stages of harvesting, handling, promotion, and distribution in order to guarantee sufficient access to food for the increasing global population. Improper handling procedures and storage facilities can cause the overall quality of food items to decrease. As a result of these issues, many developing countries experience significant losses in agricultural food production and related items. Postharvest losses in vegetables and fruits are estimated to account for 30% to 40% of the total production, significantly contributing to the rise in agricultural product prices (El-Sebaii and Shalaby 2022; Nukulwar and Tungikar 2021).

The intricate process of drying, which includes the exchange of mass and heat, is one of the primary methods employed to preserve agricultural produce. It requires a higher rate of energy, and as a result, scientists have undertaken extensive research to increase energy efficiency, accelerate the drying process, and maintain product quality. In recent times, the popularity of solar-powered dryers has increased because solar energy is an inexpensive and readily available source of power. Methods for storing thermal energy can enhance the dependability of solar energy for drying, allowing the utilization of stored energy when there is no solar exposure. Nevertheless, these experiments have incurred significant expenses due to the intricacy of every step involved in the solar drying process.

Multiple studies have supported utilizing advanced computer simulation tools to tackle this issue. These researches have yielded positive results and shown the efficiency of these techniques in various solar dryers. Hence, our objective in this chapter is to introduce parameters, examine different dryer types, and emphasize the significance and tactics for thermal energy storage (Barbosa et al. 2023).

The greenhouse industry is regarded as a sector that consumes a significant amount of energy and depends on fossil fuels, resulting in significant emissions of greenhouse gases (GHGs). Since the early 1960s, the global population has doubled and is projected to reach 9.8 billion by the year 2050. The worldwide problem of "Food Security," which is regarded as one of the most important sustainability factors, is made worse by this increase. Despite the fact that undernourishment is declining globally, hunger rates have been rising since 2014. Consequently, the number of individuals suffering from undernourishment grew from 784 million in 2015 to 821 million in 2017. Investments in the agricultural industry are required to provide food security, combat global hunger, and eradicate poverty. (Gorjian et al. 2020d; United Nations 2019). The "World Food Summit" (WFS) provided a comprehensive definition of food security in 1996, which was widely acknowledged as the following (Hassanien et al. 2016): "Food security is a situation in which all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life".

Based on the latest information from FAO in 2019, food systems globally use approximately 30% of the total energy utilized worldwide. Additionally, Around 19–29% of the annual greenhouse gas (GHG) emissions are caused by these systems' excessive reliance on fossil fuels. Agricultural greenhouse energy use has recently become a problem due to the increasing energy prices and environmental issues associated with the use of traditional energy sources. In order to lessen the reliance of greenhouses on non-renewable energy sources, the quest for alternate and clean energy sources as well as energy-saving technologies has been greatly encouraged (Marcelis and Heuvelink 2019).

Ensuring access to sufficient food is a difficult task in developing countries, even though there is a large amount of food being produced. This challenge may be due to significant losses that occur after crops are harvested, as well as uncertainty surrounding agricultural and food policies implemented by governments (Godfray et al. 2010; Munir et al. 2021). Consideration should be given to the seasonality of agricultural products in order to prevent spoiling. Certain fruits and vegetables are only available for a brief period each year and require special attention to avoid spoilage, particularly during storage. Post-harvest losses occur due to inadequate storage and transportation facilities on the farm, as well as frequent power outages during food processing and handling (Maphosa 2020).

The absence of facilities for processing crops after they are harvested at the farm level results in the deterioration of a considerable amount of perishable goods. To solve the issue of food security, it is imperative to address the loss that occurs after harvest. The cooling or freezing preservation method is utilized to effectively store perishable products at low temperatures in order to decrease microbial activity and prevent product deterioration and shrinkage. However, traditional cold storage systems require a high rate of energy for refrigeration. They are not frequently embraced by the farming community because of their excessive energy consumption. Furthermore, commercial cold storage facilities are only widely available in areas where grid electricity is accessible.

Solar energy can be used for cooling or refrigeration to preserve food. Utilizing solar energy for cooling is appealing because when there is a greater need for cooling, the sun is at its strongest. This, combined with the need to ensure thermal comfort for individuals residing in hot regions and the need for food preservation facilities, can serve as a motivating factor for further research and development in the field of solar cooling systems. The primary applications include vapor compression refrigeration, absorption refrigeration, and passive cooling. These applications may differ in terms of conditions, such as the use of continuous or intermittent cycles, energy storage on the hot or cold side, various control strategies, different temperature ranges of operation, and a range of collectors.

Reducing the losses that occur after the harvest of horticultural produce, which currently ranges from 25 to 30%, could significantly improve the availability of fruits and vegetables for consumers. Storage plays an important role in the handling of horticultural produce since it is constantly subjected to spoilage due to different endogenous and exogenous factors. The endogenous factors such as hormones, which are produced within the fruit itself, cause ripening and senescence. External factors such as the growth of microorganisms, temperature, relative humidity, air movement, and physical damage lead to significant losses in both the quality and quantity of the produce. The storage life can be prolonged by days, weeks, or even months by inhibiting these undesirable changes with either chemical treatments or modification of the storage environment. Refrigerated storage, which is one of the most effective methods for storing fruits and vegetables in their fresh state, is accessible in industrialized countries due to the presence of electricity. However, it is not readily available in the majority of the world.

The cold storage industry has developed rapidly in recent years. Despite the progress made, the industry has been facing numerous problems lately affecting its further growth. The major problems faced are inadequate supply of electricity, which is the basic raw material of the industry, uneconomical rentals fixed by different states, non-recognition as a priority industry, and denial of financial benefits at concessional rates, on electric tariffs. The primary technical issue with solar refrigeration is that the system relies heavily on environmental factors such as the temperature of the cooling water, air temperature, solar radiation, wind speed, and more. Conversely, its energy conversion efficiency is low.

Therefore, in the absence of a traditional energy source, the presence of vapor compression refrigerators connected to photovoltaic panels could offer a potential solution to this issue.

2 Some Solar Applications

2.1 Solar Drying Technologies

Energy plays a crucial role in the sustainable development and economic growth of every nation. The energy demand is increasing in almost every sector to achieve economic development. The recognition of the global energy crisis has motivated scientists and engineers to pursue the utilization of renewable energy in agriculture. The need for energy in all forms around the world is constantly increasing due to rapid industrial development. Fossil fuels, including those needed in the process of drying, continue to meet the majority of the world's energy needs (REN21 2018). Nevertheless, the adverse effects on the environment and the depletion of their resources significantly restrict their usage. Renewable energy sources have emerged as essential alternatives for attaining a more environmentally friendly and dependable energy future as a result of rising environmental consciousness and the implementation of sustainable energy policies (Achkari and Fadar 2020).

Solar energy is becoming popular due to having the highest energy potential out of all renewable sources, being cost-free, limitless, accessible, and diverse. Optimizing drying processes is important both economically and environmentally. The search for solar-powered dryers has gained popularity recently, with many countries still relying heavily on non-renewable energy sources (Bekkioui et al.. 2020). Despite the impending environmental impact, conventional fossil fuel-based dryers and kilns are still used. Solar dryers have numerous advantages over conventional kilns and dryers, in addition to their positive impact on the environment. They are easy to set up and use, can lower overall drying expenses by up to 80%, and encourage the production of higher-quality finished goods. Furthermore, they emit no greenhouse gases (Jain et al. 2023). Even though solar dryers have been shown to have positive economic and environmental effects, more studies should always be done to optimize solar energy's capture, conversion, and use. Optimizing solar energy-based dryers offers the potential for faster drying and more efficient use of energy, enabling a greater quantity of products to be dried.

One of the primary steps in the processing chain for farmers is drying, as noted by Ihediwa et al. (2022) and Ndukwu et al. (2022a, b). This process is used to either prepare products for further processing or extend their shelf life for storage. Regrettably, it has been found that the process of drying is a significant user of energy, making up 12–15% of energy usage in agriculture globally. (Catorze et al. 2022; Ihediwa et al. 2022, Samimi-Akhijahani and Arabhosseini 2018). Furthermore, it is reported that the process of drying necessitates anywhere from 6 to 30 times more energy in comparison to cooling or freezing. (Machala et al. 2022). Since fossil fuels are often utilized to provide the heat needed for drying, they also contribute significantly to carbon emissions (Ndukwu et al. 2023). Therefore, there is currently an increasing agreement to transition from dryers that rely on fuel to ones that are fueled by renewable energy sources" (Chowdhury et al. 2020; Kumar et al. 2023) to conserve the environment and its natural resources.

To achieve Sustainable Development Goals, clean technologies are being implemented across the entire energy spectrum, particularly in rural farming areas (Messina et al. 2022). These technologies aim to conserve resources, combat climate change, and reduce air pollution. The following list of renewable energy sources, as provided by Rahman et al. (2022), is as follows: "Geothermal energy, solar thermal energy, wind energy, and solar photovoltaic energy".

Reviews on solar drying can be categorized into a variety of subcategories. The use of thermal storage to accelerate drying, hybrid technologies, solar greenhouses, energy efficiency, exergy efficiency, economic evaluations, environmental evaluations (4E), software applications, crop quality attributes, and solar biomass drying are some of the topics covered in thorough reviews that cover every facet of solar drying research. The results of these evaluations are then critically analyzed, as shown in Fig. 1.

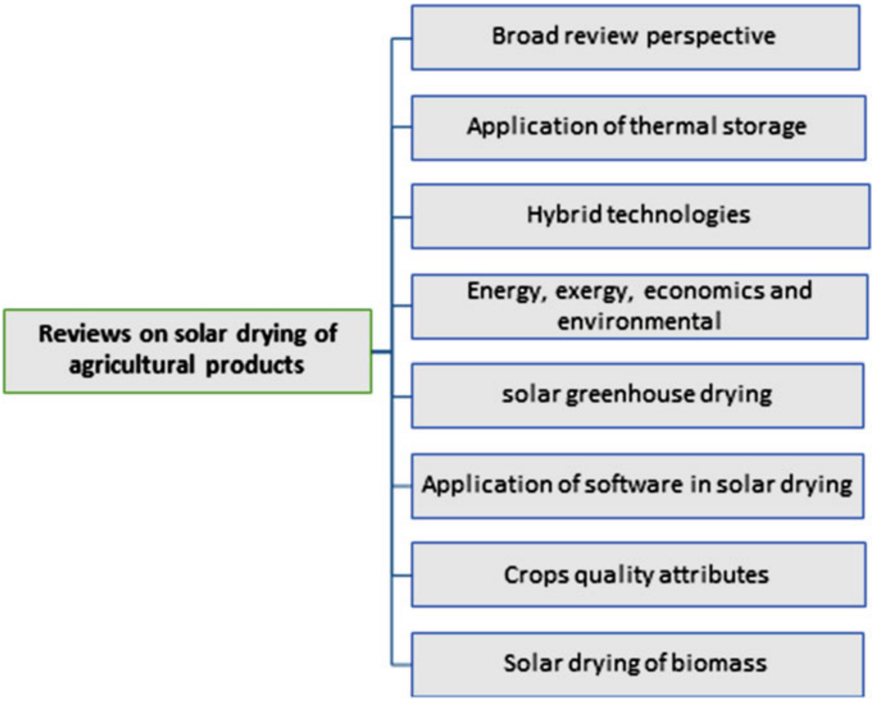


Fig. 1 Classification of thematic reviews for solar drying of agricultural products (Ndukwu et al. 2023)

Drying is a means of preserving food that involves extracting moisture from harvested goods to prevent the growth of microorganisms. Open sun drying is one of the oldest known methods for processing and preserving agricultural products, harnessing the sun's readily available and abundant energy. On the other hand, the agro-industry utilizes thermal processes for food processing and storage (Erkmen and Bozoglu 2016). Agricultural products can be solar-dried inside structures, which is an effective way to lessen quality loss and post-harvest losses that are common with conventional sun-drying methods. Advancements in sustainable growth have been made possible by the limitations of conventional energy sources and the benefits of solar energy, including its efficiency and cost-effectiveness. Solar radiation is globally available and has now replaced the conventional method of drying to preserve fruits and vegetables for longer periods. Food drying is a challenging process that involves irregularities in mass and heat transport as well as physical and chemical interactions that may have an impact on the product's quality. The adjustment and regulation of moisture levels in solid substances through drying is a crucial stage in the production of several types of chemical goods.

The field of food drying is diverse because different foods require various drying procedures. To remove excess water and increase the moisture content to the desired level, a product can be dried, whether it is natural or synthetic. This process requires a lot of energy to run. Foods usually have higher water contents than what is suitable for long-term storage, making it crucial to reduce their moisture levels. When food has less moisture, it takes longer for enzymes, bacteria, yeasts, and molds to form. This allows food to be preserved and stored for longer periods without going bad. Another example of drying food is removing all moisture until there is none left. Once the dried food is ready for use, it is rehydrated and takes on its original form (Izadi et al. 2022). A cost-effective strategy for preserving excess agricultural output is solar energy drying, particularly for crops grown in moderate to small quantities. It is environmentally friendly and is employed to dehydrate food items, agricultural products, and crops ranging from individual households to small businesses. Consequently, numerous solar drying techniques have been developed, such as direct, and indirect sun drying, and mixed-mode sun drying (Ndukwu et al. 2022a, b).

The use of artificial dryers results in an enhanced quality of dried products because it enables control over the drying air's velocity and temperature. However, these dryers also require a significant quantity of energy is required to warm and move the airflow, leading to increased capital and operational expenses (Janjai et al. 2009).

The diagram in Fig. 2 shows the different groups of solar dryers. This has greatly augmented the revenues of small agricultural farms and communities.

Phadke et al. (2015) identified two types of solar dryers: forced circulation dryers and natural circulation dryers. Sharma et al. (2021) stated that solar dryers can be categorized according to the method of air circulation or operation, the manner in which heat is transferred to the product, and the design of the dryer (Fig. 3).

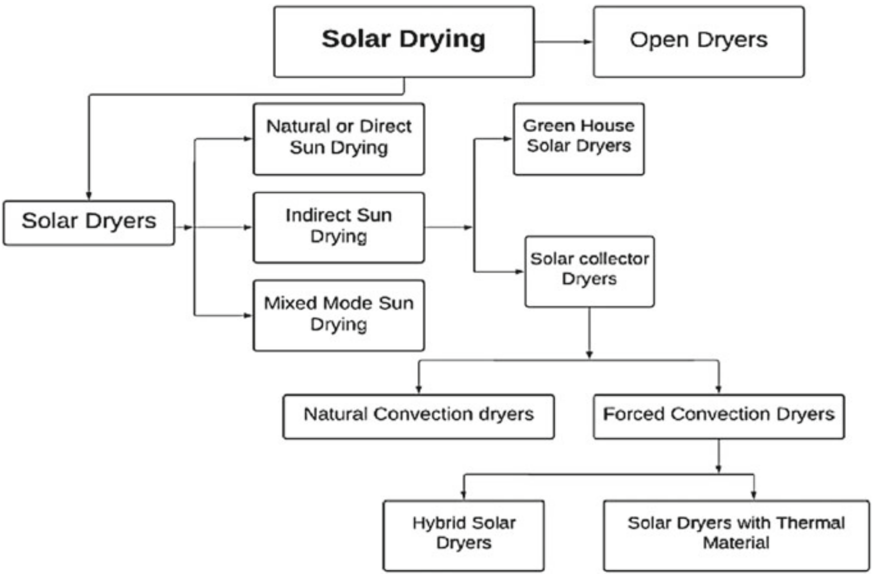


Fig. 2 Process classification for solar drying (Suresh et al. 2023)

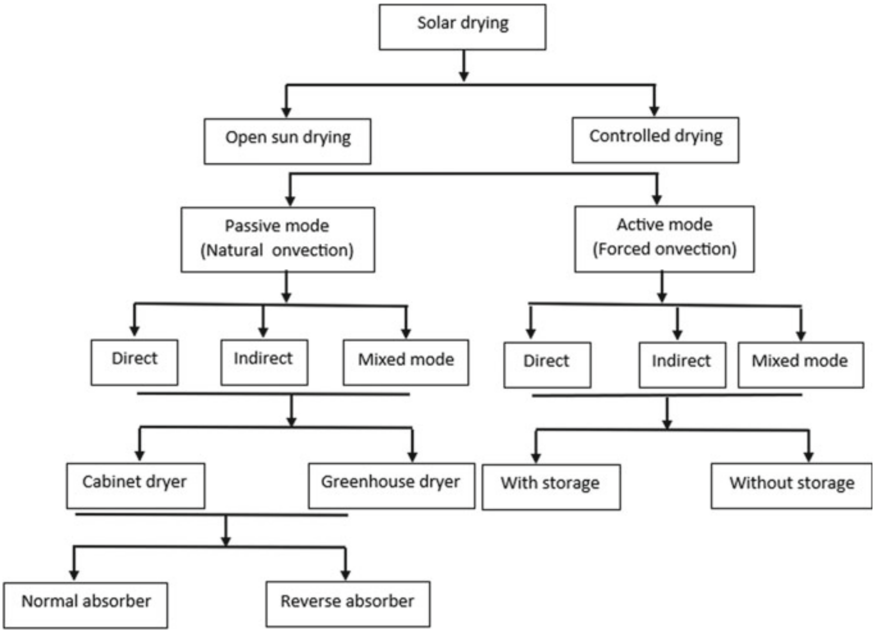


Fig. 3 Solar dryer classification (Sharma et al. 2021)

Direct solar *dryer*: The item that is supposed to be dried immediately absorbs sun energy. Hot air is provided by solar collectors and is used in the drying unit. Through a translucent sheet covering the east and west sides of the chamber, the product is exposed to solar energy. Due to direct solar exposure, this method has the potential to produce low-quality products with a black surface (Fig. 4).

Indirect solar dryer: The air that passes through the product being dried is heated by sun radiation in the system. Normally, solar radiation captured by separate solar collectors is converted into thermal energy and used to heat the air (Figs. 5 and 6). The sides of the drying chamber are insulated in this working mode to block solar radiation and simultaneously minimize heat loss through the sides (Eltawil et al. 2012).

Solar natural convection dryer: A temperature gradient causes the heated airflow. Due to the heated air's natural tendency to travel around, it is frequently referred to as a passive dryer. The addition of a chimney, where the exhausting air is heated even more, may improve the results of the solar dryer.

Forced convection dryer: "The air is pushed through a device that collects solar energy and the material being dried by a fan or blower, commonly known as an active dryer. Dryers with forced circulation typically result in quicker drying, increased airflow, and improved control over the temperature of the heated air. The dryer can

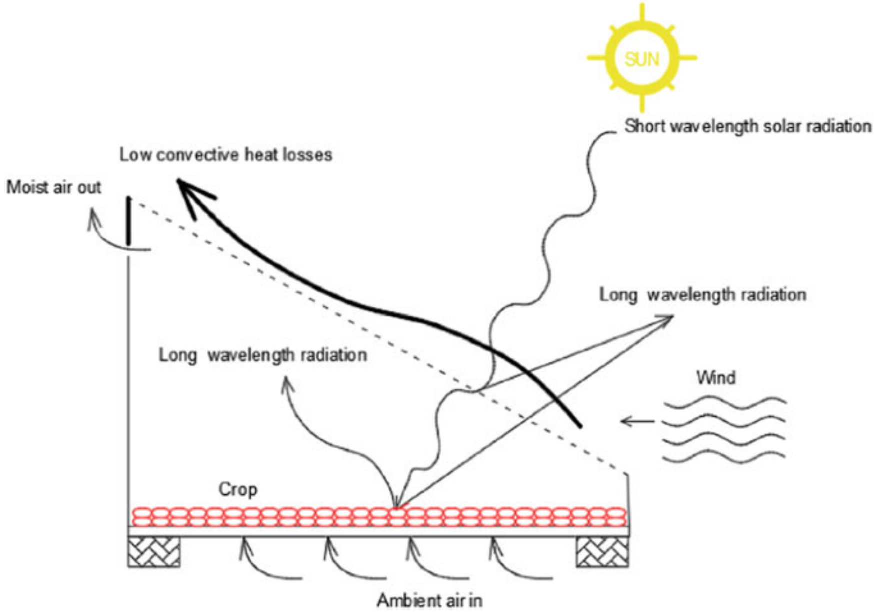


Fig. 4 Natural or direct solar drying process (Suresh et al. 2023)

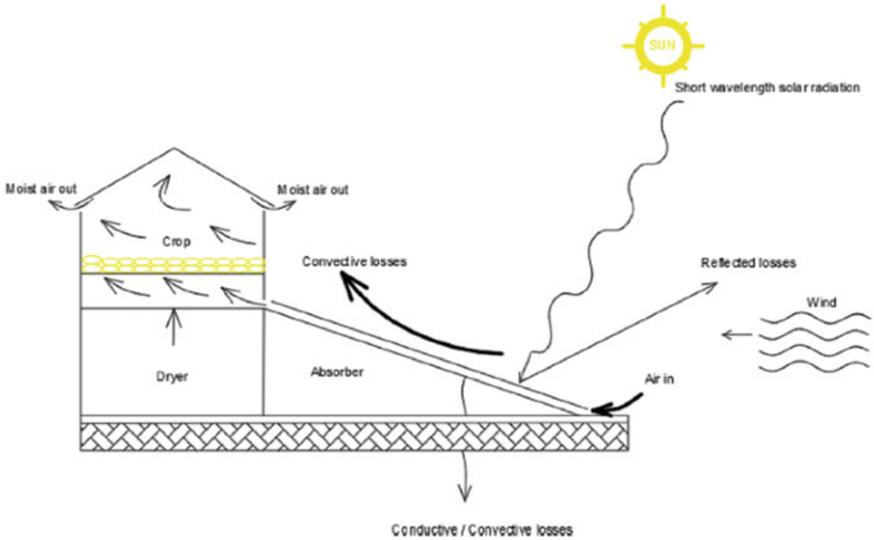


Fig. 5 Indirect solar dryer (cabinet–dryer) (Suresh et al. 2023)

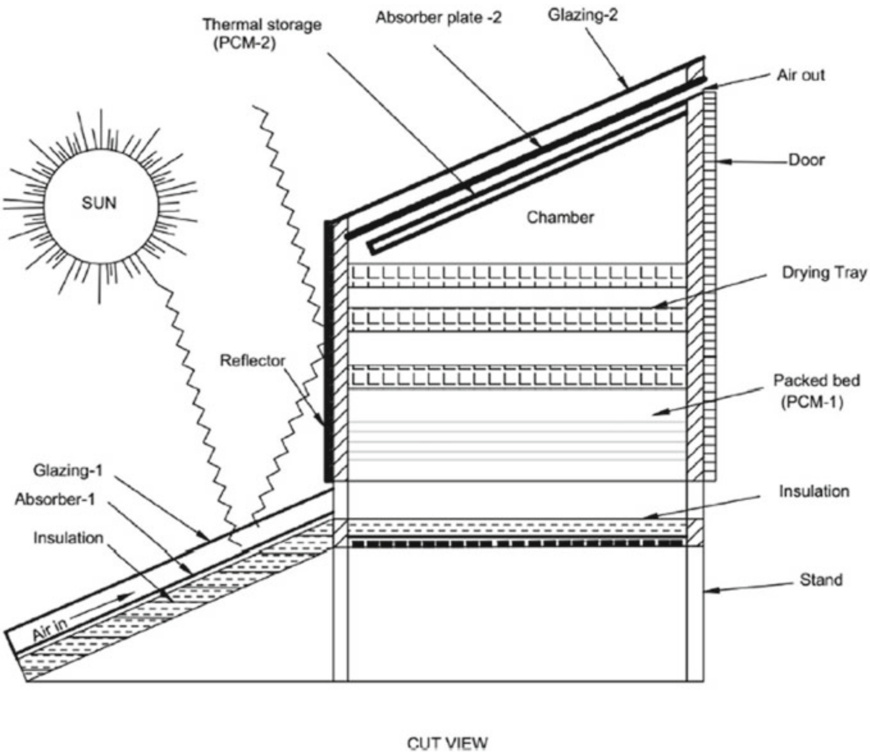


Fig. 6 Dryer with thermal storage (Chichango et al. 2023)

be customized to accommodate various volumes based on the user's requirements and the availability of open space".

Actually, the idea of forced or natural air circulation underlies the operation of these dryers. The mixed-mode natural convection solar crop dryer may be the most efficient, according to tests comparing these basic ideas. It performs especially well in humid tropical regions where the climate is ideal for drying agricultural items in the sun (Eltawil et al. 2012).

Due to the unreliable or nonexistent power supply in villages, natural convection solar dryers are favored over forced convection solar dryers for drying a variety of agricultural products at the farm level.

The benefits and drawbacks of various solar dryers, including natural, indirect, and mixed-mode drying methods, are listed in Table 1. This includes information about their construction level, dehydration rate, and economic factors.

Difficulties and Challenges

Figure 7 illustrates a number of factors that have an impact on the design, development, use, and assessment of solar dryer systems (Suresh et al. 2023) which include:

Table 1 The pros and cons of different solar dryers (adapted from Suresh et al. 2023)

S. No.	Type of the dryer	Pros	Cons
1	Natural or direct solar drying	• Easy construction, simple in loading/unloading • It protects the products to be dried • Agricultural produces can be dried during the night or in rainy conditions • The clear lid of the enclosure reduces produce contamination • The quality of the dried produces is better in comparison to sun drying outdoors	• The rodents, birds, and other animals may damage the products • The degradation occurs due to exposure to direct sun rays, rain, dust storms, and dampness • There is also pollution from undesirable weather parameters such as wind-borne debris, dirt, and dust • The damage can also result from excessive drying. Additionally, there may be insect infestations and the development of microbes • Furthermore, there are additional losses during storage due to uneven drying

(continued)

Table 1 (continued)

S. No.	Type of the dryer	Pros	Cons
2	Indirect solar drying	• The commodities to be dehydrated are slightly elevated and flat plate air solar collectors are used and achieved a higher dehydration performance • This method is suitable for small farms • The utilization of this method helps to avoid the contamination of the dried product • In comparison to the direct method, it is a solar drying technique that is substantially more effective • To maintain the quality of the product, exposure to direct solar radiation should be avoided • The drying time may vary depending on the product • The final condition of the product is not determined by natural phenomena	• High costs for construction • It needs maintenance after a certain time
3	Mixed mode sun drying	• Speed up the drying process while maintaining safe moisture levels • Compared to alternative drying methods, this method significantly reduces the required drying time	• The capacity of the dryer with agricultural food is very low • The quality of grain dried over a year is worse in comparison to grain dried utilizing an indirect dryer • The cost of maintenance is high • The capital expense is more

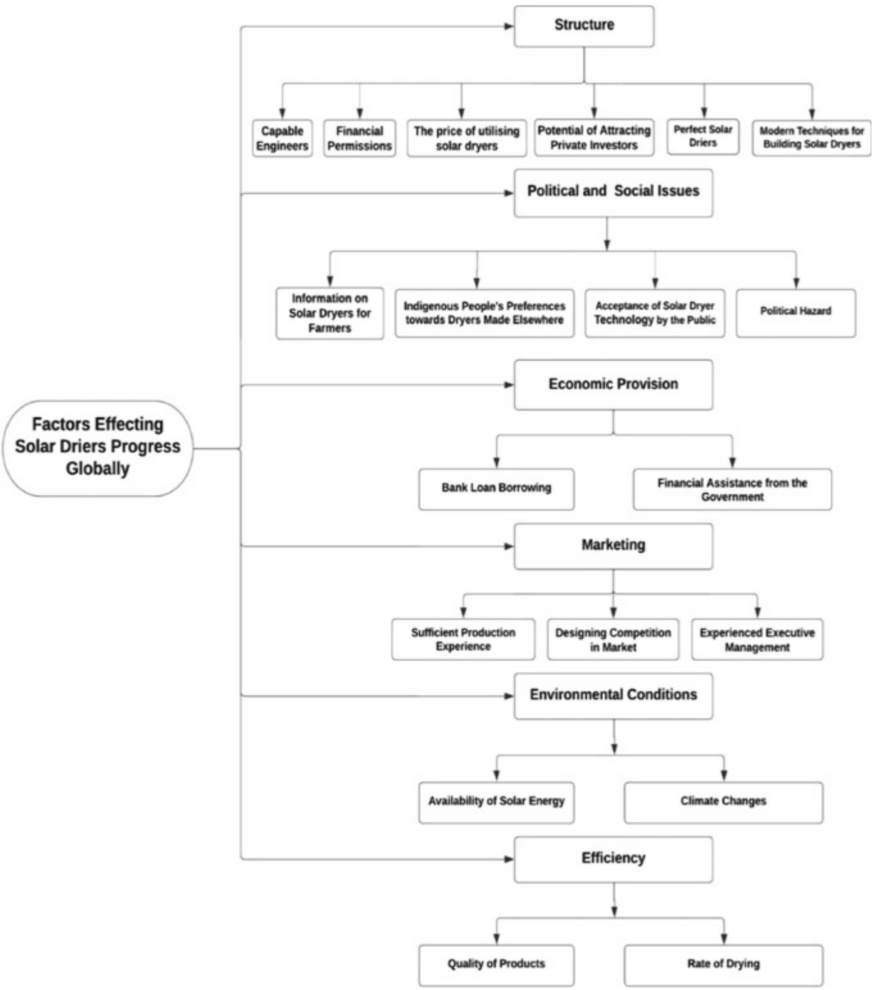


Fig. 7 Proposed factors that affect the solar dryers progress (Suresh et al. 2023)

(a) Structure (Khanlari et al. 2021; Sharma et al. 2009a, b; Solangi et al. 2011),
(b) Political and social issues (Benmarraze et al. 2015; Das and Parvathy 2022)
(c) Economic provision (Chandel et al. 2014)
(d) Marketing,
(e) Environmental condition (Das and Parvathy 2022)
(f) Knowledge and efficiency

2.1.1 Some Drying Applications:

The presence of a combination (direct/indirect) multi-tray product drying system connected to photovoltaic modules could offer a potential solution for preserving fruits/vegetable products and extending their storage duration. Eltawil and Imara (2005) designed a multi-tray and mixed-mode dryer that operated using a PV system. The designed system is suitable for rural areas. The experimental setup consisted of a solar PV module, battery, plastic solar collector, and multi-tray dryer structure fabricated and installed outdoors. Figure 8 shows an experimental multi-tray crop drying setup powered by solar photovoltaic (SPV).

Working principles: The warm air from the plastic solar collector is being pushed into the drying chamber from the bottom by a DC fan powered by an SPV (solar photovoltaic) panel. The crop receives heat from the air as it then contacts the first tray. Additionally enhancing the temperature of the crop directly, some of the solar radiation that strikes the front glazing also makes its way into the drying chamber. As a result, the dryer operates in a mixed mode. The item must be dried for two to four straight sunny days. Both batch mode and semi-continuous mode can be used to dry the product. Drying takes place from 8:00 AM to 6:00 PM. Three labeled samples were used to track the drying data. Each sample was weighed separately, then placed in the middle and on either side of each tray. When the samples' weight loss had almost come to an end, the dehydration process was paused.

To evaluate the drying system's effectiveness, a fig fruit (*Ficus carica*) was dried. The study examined three drying techniques: direct and indirect natural convection

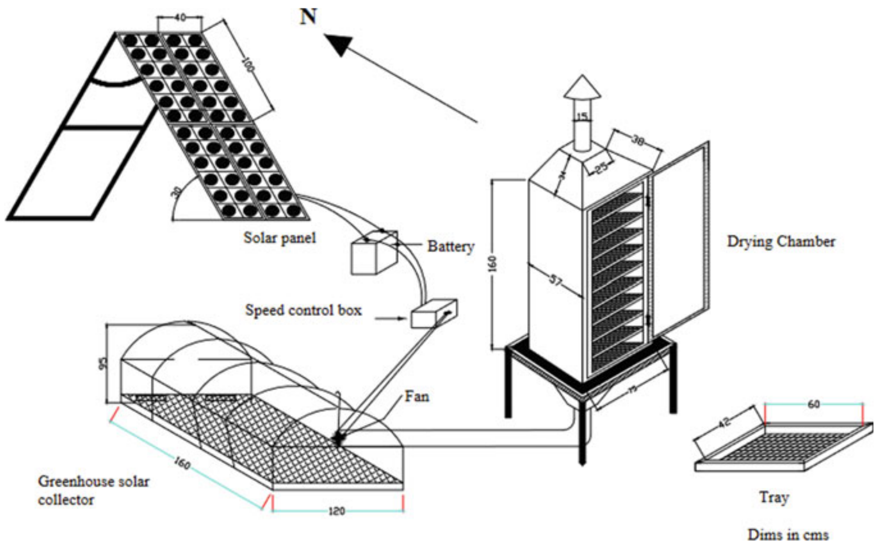


Fig. 8 Schematic diagram for SPV-powered multi-tray dehydration system for rural areas (Eltawil and Imara 2005)

drying, and drying in an electrical oven. Mixed mode forced dehydration with three distinct airflow rates (1.52, 2.15, and 3.25 m^3/min). For each treatment, the figs were treated differently, such as with 1% sodium hydroxide, 1.5% sodium metabisulfite in water, followed by drying, or drying following blanching-drying and soaking in a 70% sugar solution.

Results outcomes are summarized as follows (Eltawil and Imara 2005):

- The amount of sunlight that is being observed is sufficient to justify the investment in a mixed-mode multi-tray crop drying system that is operated by a SPV system outdoors. This system is particularly beneficial in remote areas.
- The recorded data shows that at 13:00, the average maximum power output of 139.35 W, and the corresponding average maximum insolation of 963.12 W/m^2 on the panel surface.
- It has been discovered that when the module temperature increases, the short-circuit current increases while the open-circuit voltage slightly decreases.
- The average daily PV conversion efficiency of 8.76% corresponding to an average panel temperature of 47.55 °C was recorded for clear sunny days. By 16.61 °C, the daily average panel temperature was greater than the outside temperature.
- On clear sunny days, a daily average PV conversion efficiency of 8.76% was found, which corresponds to an average panel temperature of 47.55 °C. Additionally, the average daily panel temperature was found to be 16.61 °C higher than the ambient temperature.
- For varied airflow rates of 1.52, 2.15, and 3.25 m^3/min, respectively, the average daily panel energy output of 1.28 kWh per day exceeded the daily load energy demand by 50.4, 44.3, and 39.61%.
- The maximum stagnation temperature attained in the dryer was 67.4 °C for an empty mixed mode natural convection dehydration system when the dryer outlet was closed. The results observed indicate that the obtained dryer temperature can be used for drying horticulture products since a drying temperature within the same range is needed.
- Under natural convection for an empty drying system (i.e. drying under shaded conditions) and the air outlet of the dryer was opened, the variation of temperature was limited to one degree.
- Under the batch mixed mode forced convection system, it was found that the highest and minimum values of air temperature inside the plastic solar collector and the dryer were recorded at airflow rates of 1.52 and 3.25, m^3/min, respectively. So, it is recommended to increase the area of the plastic solar air collector hence variation of air temperature inside the collector can be minimized.
- The best pretreatment for the dehydration of figs was with a 1.5% aqueous solution of sodium metabisulfite since it required the shortest dehydration time to reach the equilibrium and safe moisture content.
- Rehydration process revealed that the lowest and highest rehydration ratio was observed with pretreatments of 1% sodium hydroxide followed by 1.5% aqueous solution of sodium metabisulfite and 1.5% aqueous solution of sodium metabisulfite only, respectively.

- It has been possible to construct multiple regression equations that can be utilized to forecast SPV and other dehydration system performance.

Potato chips are highly popular fried snacks. Their distinctive crispy texture is one of the most crucial factors determining the quality of the final product. This texture is primarily influenced by the quality of the raw materials and the parameters used in the technological processing (Kita 2002). The temperature at which frying is done and the type of oil used have a known impact on the dried potato crisps. Decreasing the frying temperature can be beneficial in preventing certain negative qualities like the creation of acrylamides, which are known to potentially be cancer-causing substances (Gertz and Klostermann 2002).

Peppermint oil is a highly popular and commonly used essential oil due to its key components: menthol and menthone. It finds applications in flavoring pharmaceuticals and oral preparations. Consequently, the appropriate method of conserving peppermint through dehydration is crucial in preserving its properties.

A solar cabinet dryer (SCD) that combines solar and wind energy was conceived, manufactured, and tested by Eltawil et al. (2012) to dry horticulture items and medicinal herbs. To improve the airflow, they added a flat plate solar collector and a vertical solar chimney that had been blackened. To further enhance the circulation, they added a suction axial fan that was powered by wind. The researchers evaluated the performance of the SCD with and without a load, using potato chips and peppermint as examples. To compare results, they also dried the products separately using traditional methods: open sun drying, the SCD, and an electric oven.

Passive solar cabinet dryer: A solar collector is used to capture solar energy, which is then directed into the cabinet in the solar cabinet dryer. The heated air is then used to heat a larger volume of air, which is then moved by natural convection through a drying chamber. As a result, the product receives direct and indirect heating from the sun's light. As shown in Fig. 9, this solar dryer was created, built, and assembled. A solar cabinet, a flat plate solar collector, air vents, and dryer stands are some of its numerous parts. A hardwood drying chamber, two shallow perforated trays made of 0.5 cm mesh stainless steel wire screen stacked one on top of the other, a clear glass cover (5 mm thick glass sheet), and a chimney equipped with a suction axial fan that can be powered by wind are all parts of the solar cabinet drier. A flat plate solar collector is connected to the cabinet drying chamber at the bottom (plenum chamber) from the front side. The front glazing of the cabinet allows some sun radiation to enter the drying chamber, raising the warmth of the crop even further. As a result, the dryer operates as a mixed mode type by fusing components from both direct and indirect solar drying systems.

The top of the cabinet drying chamber was connected to a vertical cylindrical solar chimney that was constructed of galvanized iron and painted matte black. Convectional airflow was facilitated and controlled. Through natural convection, this design increases airflow throughout the entire building by reducing the density of the air in the chimney. The solar chimney was equipped with an axial fan to improve airflow even further. This fan uses wind energy to run, which produces a suction effect. The suction fan was driven by a little windmill. The chimney's center

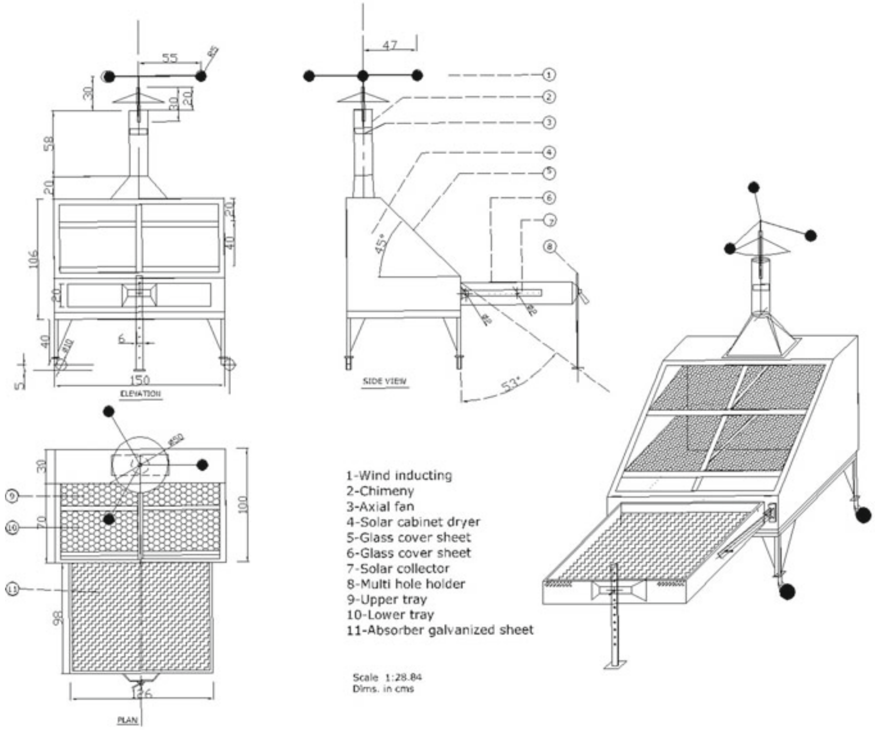


Fig. 9 Schematic diagram for the newly created solar-wind ventilation cabinet dryer (Eltawil et al. 2012)

held a vertical steel shaft with a 1 cm diameter on which the windmill was mounted. Three lightweight stainless steel cups with a diameter of 10 cm each made up the windmill and were fastened to the top of the steel shaft. These cups form a rotor with a diameter of 115 cm by rotating horizontally on a vertical pivot shaft. A metal lid with a 50 cm width in the shape of an inverted parabola covers the top of the chimney to keep dust and rainfall from entering the drying compartment. In order to reduce frictional resistance, ball, and footstep bearings were used. With the aid of a wind draft, the shaft of the suction fan is immediately rotated. Figure 9 shows the chimney's specifics in detail.

The bottom of the solar cabinet drying chamber is where the warm air from the solar collector is directed. When it hits the first tray, the crop absorbs its heat. The product on the second (higher) tray receives the air's sensible heat after which it is transferred before naturally exiting the cabinet at the top. Some of the sun energy that strikes the cabinet's front glazing enters the drying chamber and directly raises the temperature of the crop. During the dehydration process, the airflow rate can be increased by using a suction axial fan that relies on the natural wind for assistance. As a result, the dryer operates as a mixed mode type.

A full day of sunny, clear weather is needed for the product to dry, potentially less. Although it was done in batches, drying can also be done in a semi-continuous manner. Drying lasts from 9:00 am to 6:00 pm, or until the samples' weight loss almost ceases. Three weighed, labeled samples were weighed and placed in the middle of each tray to serve as a drying progress indicator.

According to the findings, the collector's tilt angle of 60° produced the maximum temperature for drying air, which was then followed by the dehydration system's tilt angle of 30°. The created solar collector dehydrator (SCD) proved capable of drying the chips and peppermint to a safe moisture level in around nine to ten and six hours (about one sunny day), respectively. With a 15-s fry time, the chips' best color was obtained. The panelists enjoyed the fried chips and dried peppermint. Superior quality for the dried goods is ensured by the SCD. The increased SCD is regarded as a viable method for drying potato chips and peppermint when taking into account elements like electricity requirement, frying time, health conscience, and exploitation of solar energy.

2.2 *Greenhouse Technologies and Applications*

Sunlight passes through the cover and strikes the opaque surfaces inside a greenhouse, which is an enclosed enclosure covered with materials like glass, fiber-reinforced plastic (FRP), and polyethylene film. This sunlight is then transformed into heat to some extent. Due to the heat trapped within the greenhouse, the air temperature increases, creating optimal conditions for plant growth (Syed and Hachem 2019). High production and efficiency arise from safeguarding the cultivated plants from severe outside conditions, pests, and diseases.

According to multiple factors, including size, orientation (east–west or south-north), coverage/shading and building materials, applications, and the technology employed to regulate the microclimate (methods either on-site or remote) (Ghani et al. 2019; Sahdev et al. 2019), Greenhouses can be classified into two categories: greenhouses for crop cultivation and greenhouses for crop drying. The purpose of crop-drying greenhouses is to produce dried crops of higher quality compared to the traditional method of drying under the sun. (Khanlari et al. 2020), Crop production greenhouses allow for year-round growing of vegetables, fruits, and flowers, even during the off-season (Yano and Cossu 2019).

In 2019, the United Nations' "Food and Agriculture Organization" (FAO) published the Early Warning Early Action (EWEA) report. The paper offers a thorough examination of the major dangers to the agricultural sector and global food security. According to this report, political unrest and climate-related calamities have a cumulatively harmful impact on food availability and production in several nations and areas. There is increasing evidence that climate change is presently affecting agriculture and food security, especially in nations with agricultural systems that are more susceptible to damage. Based on specific studies (Gorjian et al. 2020c; Veldhuizen et al. 2020), it has been found that the expansion of the agricultural sector is up to 3.2 times more efficient in reducing poverty compared to the growth of other sectors. The agricultural industry is also facing another important concern, which is the creation of "Sustainable Food Systems" (SFSs). These systems require a consistent energy supply to address the problem of unpredictable fuel expenses and improve food security (Nguyen 2018; Vadiee and Martin 2013). Agriculture's social, economic, and environmental goals, as well as those of other economic sectors, must all be recognized and balanced for agricultural and food systems to be sustainable (Compassion in World Agricultural 2008). All stages of the food chain rely on energy, including crop cultivation, forestry, dairy production, post-harvest applications, food storage, processing, transportation, and distribution. (Gorjian et al. 2020d).

Recently, renewable energy sources have shown significant potential for integration with traditional greenhouse designs. Solar energy can be considered a feasible option for integrating with agricultural greenhouses because it is a sustainable, expandable, and reliable renewable energy source that has no adverse environmental effects. By lowering the energy dependency of greenhouse agriculture systems on conventional resources in this way, the adoption of solar technology can help to reduce GHG emissions. Until recently, several academics have investigated certain solar technologies used in greenhouse buildings to perform studies on solar greenhouses.

2.2.1 Energy Consumption of Greenhouses

According to Acosta-Silva et al. (2019) and Golzar et al. (2018), the energy consumption in greenhouses can account for up to half of the production costs and be a factor in the second-highest operational costs. Heating, cooling, ventilation, fogging, appropriate shading, lighting mechanisms, and CO_2 enrichment systems are required to create the ideal growing conditions within the greenhouse (Hassanien et al. 2016).

All these pieces of equipment consume energy but heating and cooling applications demand about 65–85% of the supplied energy (Ahamed et al. 2019; Yano and Cossu 2019). Therefore, incorporating energy-saving technologies is a difficult task in greenhouse applications. The search for more dependable and sustainable alternative energy sources has been prompted by the drawbacks and high costs of fossil fuels (Mostefaoui and Amara, 2019). "In commercial greenhouses, the energy input is accounted for both directly and indirectly, and the energy output is equal to the product's energy value.“ According to Djevic and Dimitrijevic (2009) and Pahlavan et al. (2012), the Energy Ratio (ER), a measure of how efficiently energy is used in greenhouses, can be computed as follows:

$$ER = \frac{Energyoutput\left({MJ}/{m^2}\right)}{Totalgreenhouseenergyinputs\left({MJ}/{m^2}\right)} \quad (1)$$

The energy productivity (EP) can also be utilized for comparing the productivity of commercial greenhouses under various energy management scenarios in the following manner (Djevic and Dimitrijevic 2009; Pahlavan et al. 2012):

$$EP = \frac{Greenhouse\ Productivity\ yield\ \left(kg/m^2\right)}{Total\ greenhouse\ energy\ inputs\ \left(\mathrm{MJ/m^2}\right)} \quad (2)$$

Also, the Net Energy (NE) output can be used to compare the commercial greenhouses as follows (Djevic and Dimitrijevic 2009):

$$\text{Net Energy (NE) output} = \text{Total greenhouse energy output (MJ/m}^2\text{)} - \text{Total greenhouse energy input } (MJ/m^2) \quad (3)$$

2.2.2 Solar Greenhouses Technologies

Solar energy is now a competitive substitute for carbon-based conventional fuels thanks to several impressive breakthroughs in solar technology (Loni et al. 2020; Mirzamohammadi et al. 2020). Solar thermal and PV technologies are the two primary categories of solar energy technology. In solar thermal technology, flat-plate and concentrating solar collectors convert solar radiation's energy into heat, which can then be stored for use in a variety of domestic, residential, and commercial applications (Mekhilef et al. 2011). PV systems can convert sunlight directly into electricity because they use semiconductors.

Thermal and PV applications in agriculture both aim to increase profitability in this sector through enhanced yields, decreased losses, quicker production, and better resource management (Mohsenipour et al. 2020). Passive greenhouses and active greenhouses are the two types of solar-powered agricultural greenhouses.

By integrating solar systems like PV, PVT, or solar thermal collectors, active solar greenhouses (ASGs) are intended to increase the absorption of solar energy. In contrast, passive solar greenhouses (PSGs) seek to enhance solar energy absorption (Gorjian et al. 2020d). Using thermal energy storage (TES), the overall thermal performance of the greenhouse may be increased in either design.

Compared to active solar greenhouses, PSGs feature more straightforward architecture. Conversely, according to Shukla et al. (2016), active solar greenhouses have reduced capital and operating costs. Active greenhouses do, however, have better thermal performance, which can help offset some of the expenditures and boost their profitability.

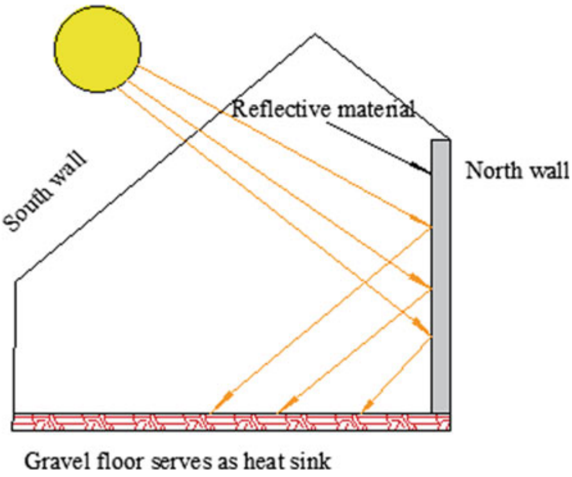


Fig. 10 Schematic view of a typical passive solar greenhouse (PSG) (Solar Greenhouses 2020)

2.2.3 Passive Solar Greenhouses (PSGs)

Li et al. (2018) claim that depending on where the sun is in the sky, different amounts of solar radiation are absorbed by the greenhouse in PSGs. The length of the south-facing wall is extended along the east–west axis, as shown in Fig. 10, to maximize the amount of wall area that is exposed to the sun.

To prevent heat loss and produce shadows inside the greenhouse, the east and west-facing walls' areas have been lowered (Çokay et al. 2018). PSGs frequently include thermal collecting elements, allowing the greenhouse to absorb solar radiation during the day and send any surplus heat to heat-storage materials including water, rock bed, soil, and phase change materials (PCMs), so maximizing the solar gains. According to Gorjian et al. (2021), the water heat storage units-which frequently resemble water-filled plastic bags-are placed either outside or indoors on the ground between rows of crops and along the north side of greenhouses. A PSG's overall effectiveness is influenced by a number of variables, including the size of the greenhouse, the materials used for the cover, the type of cultivation, and the location of the greenhouse's installation.

2.2.4 The Greenhouse Integrated PV

An emerging technique that helps greenhouses lessen their dependency on fossil fuels is the usage of PV systems. Similar to how they are connected to buildings, solar PV modules can be attached to greenhouses, but this requires different techniques because sunlight must enter the greenhouse through transparent cladding (Allardyce et al. 2017). Furthermore, a consistent and dependable energy source is needed for greenhouses. Distributed energy resources (DER) like solar and wind power systems would be suitable alternatives as a result (Callejon-Ferre et al. 2011).

The two main types of solar PV systems connected to agricultural greenhouses are on-grid and off-grid systems. The electricity generated by the PV modules in on-grid PV systems is used directly by the greenhouse, with any extra energy being fed into the power grid (Fig. 11a). Off-grid methods can be utilized to generate electricity when utility power isn't accessible (Gorjian and Shukla 2020). This kind of PV system often uses a backup battery bank in addition to a fossil-fueled generator (Fig. 11b). In greenhouses, grid-connected photovoltaic (PV) systems are the most commonly used. However, integrating with off-grid systems is the optimal choice for installing in areas where the electric grid is inaccessible due to long distances or challenging topography (Eltawil and Zhao 2010; Perez-Alonso et al. 2012).

2.2.5 Greenhouse Integrated PV Thermal

The Greenhouse Integrated PVT (GHIPVT) Solar PV modules are capable of converting sunlight into energy with an efficiency of 15% to 18%. The quantity of solar energy wasted as heat as a result of this process, however, significantly reduces power generation and raises the surface temperature of the PV module (Debbarma et al. 2017; Shakouri et al. 2020). Being both an electrical generator and a thermal collector has advantages for a hybrid PVT module. By removing excess heat from the PV module through the use of the cooling medium, which is frequently air or water, this hybrid collector boosts overall electric efficiency. The extracted heat can then be used for low- to medium-temperature applications (Gorjian et al. 2020b). Figure 12 gives an overview of PVT modules.

Concentrating PVT (CPVT) modules use curved reflectors or refractors (Fig. 13) to direct solar energy onto the multijunction (MJ) or non-silicon solar cells, with potential efficiencies approaching more than 40%. The exceptional optical and thermal efficiencies of CPVT modules make them among the most effective hybrid collectors (Daneshazarian et al. 2018).

2.2.6 Greenhouse-Integrated Solar Thermal Collectors

Solar thermal applications have attracted considerable attention due to their remarkable energy conversion efficiency and energy storage density. Solar collectors and thermal energy storage units are the two primary parts of solar thermal systems (Ketabchi et al. 2019). Thermal collectors are utilized in greenhouse applications to absorb solar radiation and generate heat, which can then be transferred to the interior of the greenhouse. This provides an optimal thermal environment for the plants cultivated within. (Gorjian et al. 2020a). Additionally, the generated thermal energy may be saved in an energy storage system for usage at night or on overcast days. According to Sethi and Sharma (2008), there are two basic types of solar thermal collectors: non-concentrating and concentrating varieties. Figure 14 depicts a categorization of non-concentrating solar thermal collectors.

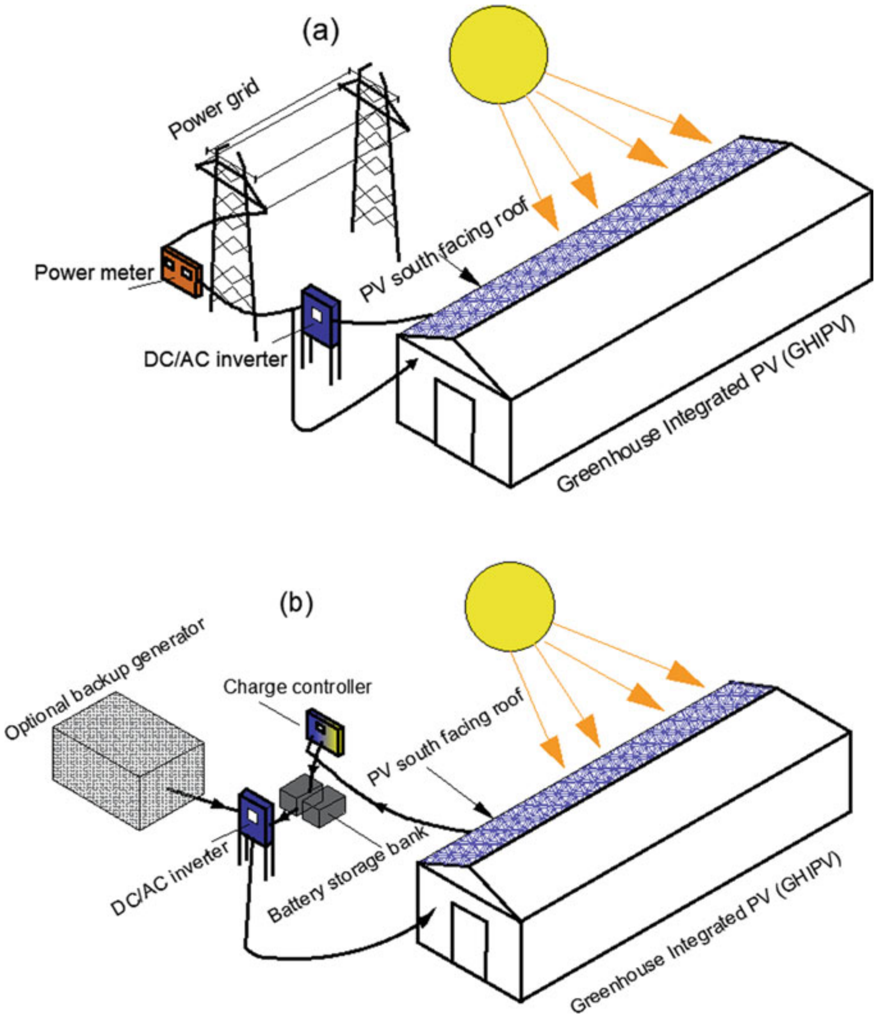


Fig. 11 Typical configurations of a GHIPV system; **a** on-grid GHIPV system, **b** off-grid GHIPV system with a backup generator and batteries

2.2.7 Solar Greenhouses with Thermal Energy Storage Integrated

Thermal Energy Storage (TES) devices enhance the performance of solar-powered greenhouses, according to Kant and colleagues (2016b, 2017). These systems accomplish this by storing the extra heat generated during daytime operations, then using the energy throughout the night and on overcast days. For this reason, some individuals believe that a capable and reasonably priced TES is a crucial component of solar greenhouses. Sensible, latent, and chemical energy storage are the three fundamental ways to store heat, according to Hosseini et al. (2018). A list of the fundamental TES

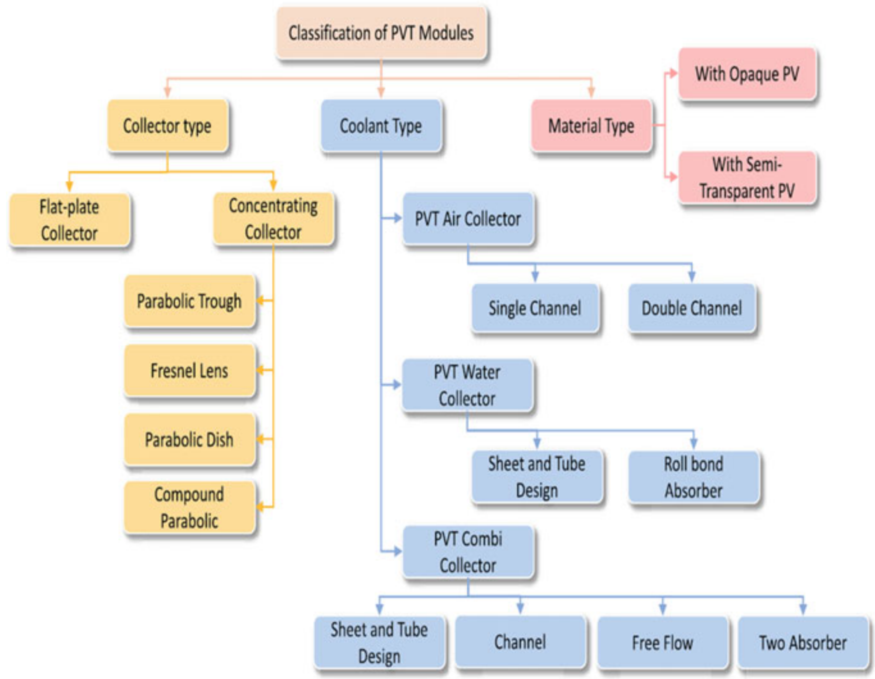


Fig. 12 Classification of solar PVT modules, from (Diwania et al. 2019)

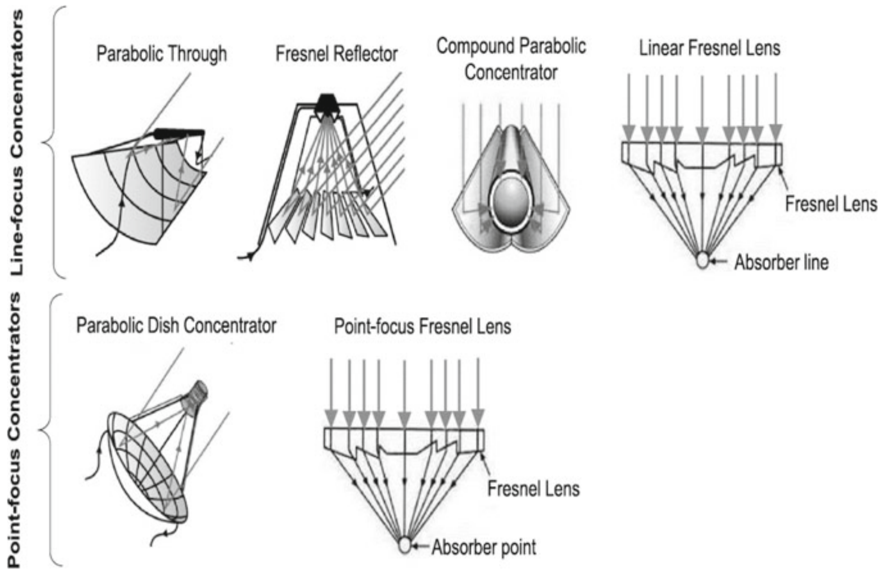


Fig. 13 Different types of solar concentrators which are used in CPVT modules (Gorjian et al. 2021)

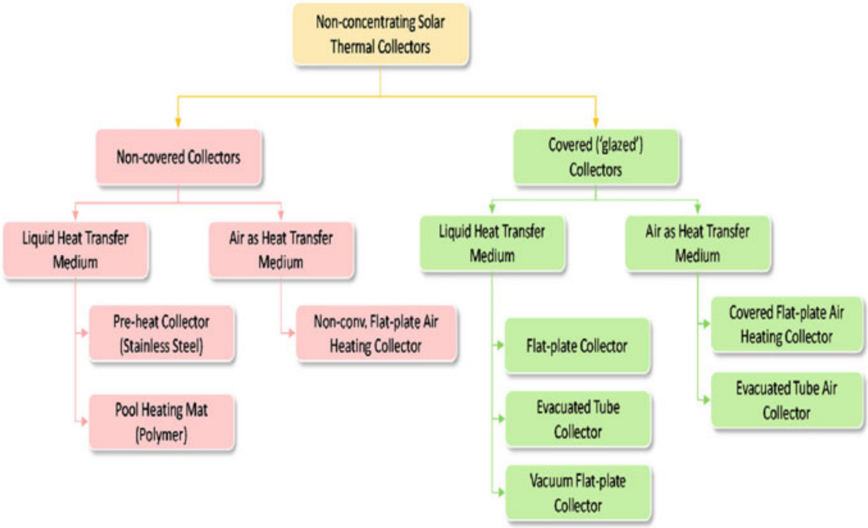


Fig. 14 Classification of non-concentrating solar thermal collectors (Fortuin and Stryi-Hipp, 2012)

methods is shown in Fig. 15. Solar flat plate collectors (FPCs) were used by Bargach et al. (1999) to create a heating system that enhanced the environment within a greenhouse (Fig. 16).

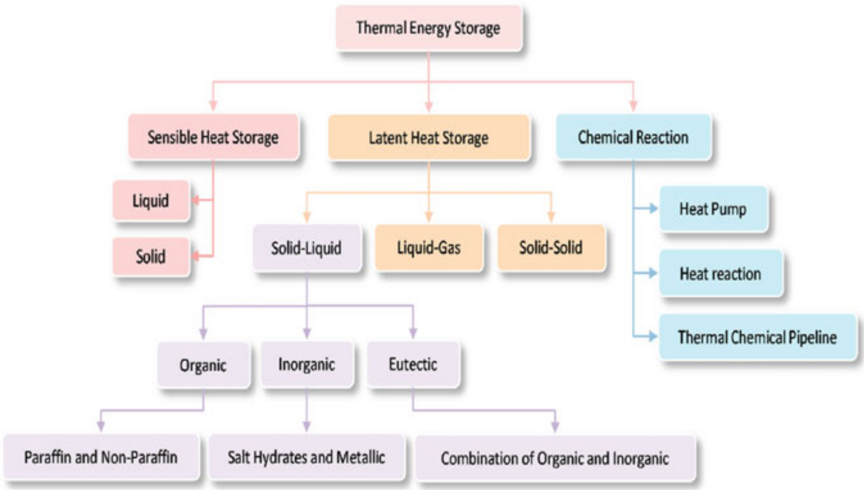


Fig. 15 TES system classification, modified from Sharma et al. (2009a, b)

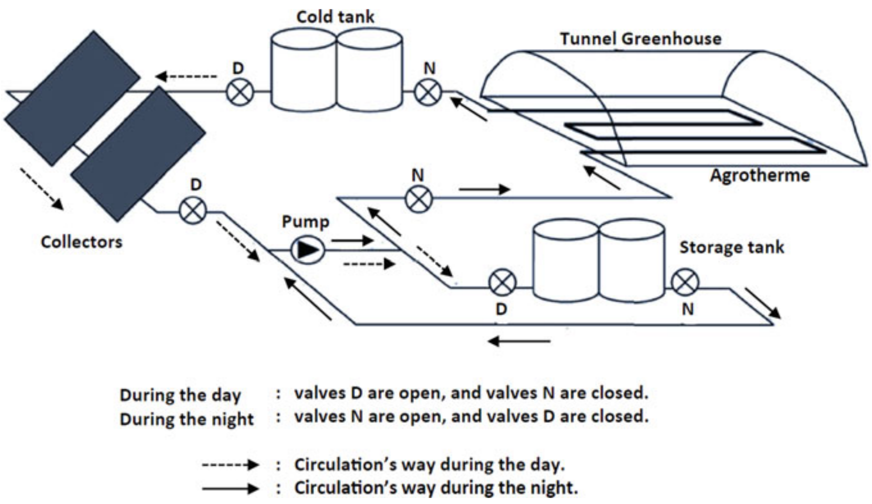


Fig. 16 The greenhouse tunnel equipped with a solar flat plate collectors (FPCs) heating (Bargach et al. 1999)

2.2.8 Greenhouse Cooling

The recognition of the global energy crisis has led scientists and engineers to focus on harnessing alternative energy sources. Solar energy is one such promising source, and efforts are being made to utilize it for domestic, agricultural, and industrial purposes.

Due to its many advantages, solar photovoltaic (SPV) technology has a huge potential for capturing solar energy. These benefits include simple and environmentally beneficial solar cell electricity generation. In order to reduce carbon dioxide (CO_2) emissions and give off-grid rural populations access to high-quality electricity, SPV must be developed and widely used. However, it is important to considerably lower the cost of SPV electricity in order to reach broad use.

In tropical and subtropical locations or in places with difficult climatic conditions, a greenhouse is an effective method for sustaining food output. When it's hot outside, a greenhouse's internal temperature rises and goes above optimal levels as a result of the heat that enters the structure.

The crops, soil, and greenhouse construction elements (shown in Fig. 17) absorb the solar radiation that enters the greenhouse. Subsequently, these warm objects release the energy back outwards. The extent of heat loss through radiation depends on the glazing material used, the surrounding temperature, the cooling/heating systems employed, and the level of cloud cover present.

The exchange of energy between a greenhouse, which contains a crop, and its surroundings can be achieved through various cooling systems. These systems include ventilation shading and evaporative cooling. Evaporative cooling, in particular, is commonly used in greenhouses due to its simplicity and controllability. There

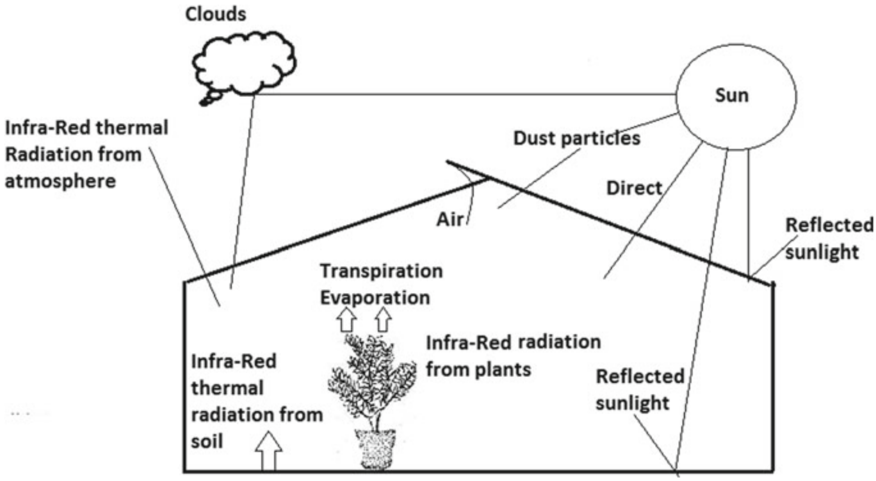
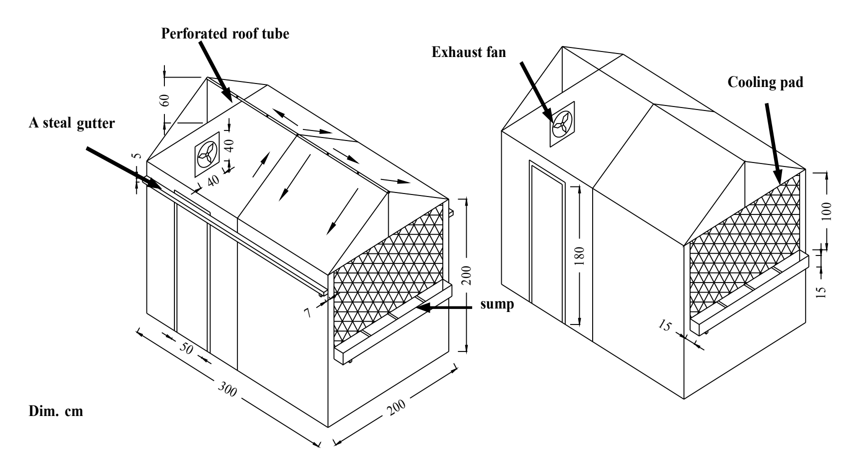


Fig. 17 Energy transfer between the environment and a greenhouse with a crop produced inside

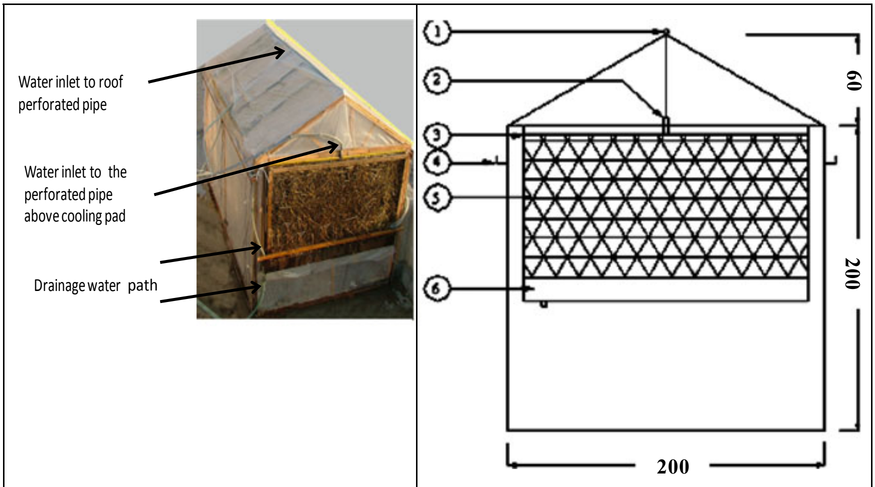
are several methods of evaporative cooling currently utilized, including fogging, the fan-pad method, and misting. These methods work by increasing heat and mass transfer rates by using fans to force air movement across a larger surface area of liquid water, promoting evaporation. The porous pad used in the fan-pad method can be wetted either by water flow or by dripping water onto its upper edge. However, commercially available pad cooling materials tend to be complex, expensive, and not easily accessible. As a result, it becomes necessary to investigate and assess the suitability of locally available materials in agricultural areas for use as alternative cooling pads. Various researchers have studied the feasibility of such alternative cooling pads for greenhouse use.

Helmy et al. (2013) built a greenhouse with an evaporative cooling system to minimize the effects of heat stress. They designed and installed two small-scale greenhouses on the roof of a house. Both greenhouses utilized a fan-pad system for cooling. However, they experimented with a hybrid system in one of the greenhouses by applying a thin water film on the roof between two layers of polyethylene cover and fan-pad. This setup aimed to analyze the impact of the roof water film on the cooling effectiveness, as shown in Figs. 18 and 19. The identical circumstances were used to compare the two cooling systems. *Cyperus alopecuroides* Rottb (Samar), *Cyerus alternifolius* (Purdy), and *Cyperus Rotundus* l (Nut-grass or Se'd) were three new materials for evaporative cooling pads that were gathered from the field, modified, and tested. The different characteristics of the newly adapted cooling pad materials are given as follows: Cyperus Rotundus l (Nut-grass or Se'd) is available in the agricultural field, triangle in shape, and hollow structure. Cyerus Alternifolius (Purdy) is available in ditches, channels, and drainage; semi-circle in shape, and spongy structure. Cryperus Alopecuroides Rottb (Samar) in the agricultural field, triangle in shape, and solid structure.



(A)) Roof water flow system with fan-pad system	**(B)** Fan-pad system.

Fig. 18 The two experimental greenhouses that will be cooled are shown in a schematic diagram (Helmy et al. 2013)



System that combines a hybrid roof water flow with a fan-pad and uses Se'd as an evaporative cooling substance.	1. Perforated pipe on top, 2. Water control valve, 3. Perforated pipe, 4. Gutter, 5. Cooling pad, 6. Sump).

Fig. 19 Picture and schematic diagram of hybrid cooling systems arrangement (dimensions in cm) (Helmy et al. 2013)

To examine the cooling performance, two different thicknesses of 10 and 15 cm were used, with air velocities on the pad faces ranging from 0.45 to 1.01 m/s. Each greenhouse had a vertical evaporative cooling pad attached to it. The second greenhouse combined roof water flow and a fan-pad system, whereas the first one ran on a fan-pad system.

The researchers measured and recorded the dry and wet bulb temperatures at nine locations within each greenhouse. They also measured the energy consumption of the cooling system under various operating conditions. Additionally, they recorded the environmental parameters outside the greenhouse, including outside solar radiation, dry bulb temperature, wet-bulb temperature, and relative humidity.

The greenhouse cooling efficiency can be calculated as follows (Koca et al. 1991):

$$\eta_{cool} = \frac{(T_o - T_i)}{T_o - T_{owb}} \times 100 \tag{4}$$

where:

η_{cool} = the greenhouse cooling efficiency, %

T_i and T_o = the dry temperatures of air inside and outside the greenhouse, °C, respectively, and T_{owb} = wet bulb temperature of outside air, °C."

According to the findings, the suggested cooling pads in the evaporative cooling systems might keep greenhouse model microclimates at a tolerable range. Particularly, it was discovered that the Se'd pad material reduced temperature more successfully. The temperature within the greenhouse was found to be lower than that of a fan-pad greenhouse in the morning and afternoon by about 1.1–5.44 °C, respectively, when operated using a combination of roof water flow and a fan-pad system. The air relative humidity increased due to the cooling system, which prevented excessive transpiration and crop damage. The Se'd, Purdy, and Samar pad materials were able to attain daily average cooling efficiencies of 88.4, 83.1, and 79.6% over testing days in the hybrid system at a 15 cm pad thickness and 0.45 m/s pad face air velocity. In comparison to other materials, the Se'd pad material showed the maximum efficiency and might be used as an alternative.

2.3 Solar Refrigeration Applications

Solar cooling can play an important role in the handling and usage of agricultural products, such as crop storage. (Eltawil and Samuel 2007a, b; Eltawil et al. 2023), medicine storage, and vaccine or drug preservation (Abdul-Wahab et al. 2009), ice making, and air conditioning.

Solar cooling can be classified into two primary methods: PV-powered cooling systems (Eltawil and Samuel 2007a, b; Eltawil et al. 2023; Saidur et al. 2008), and adsorption, desiccant, and absorption (Kalkan et al. 2012). Figure 20 shows different cooling cycles incorporated with PV systems.

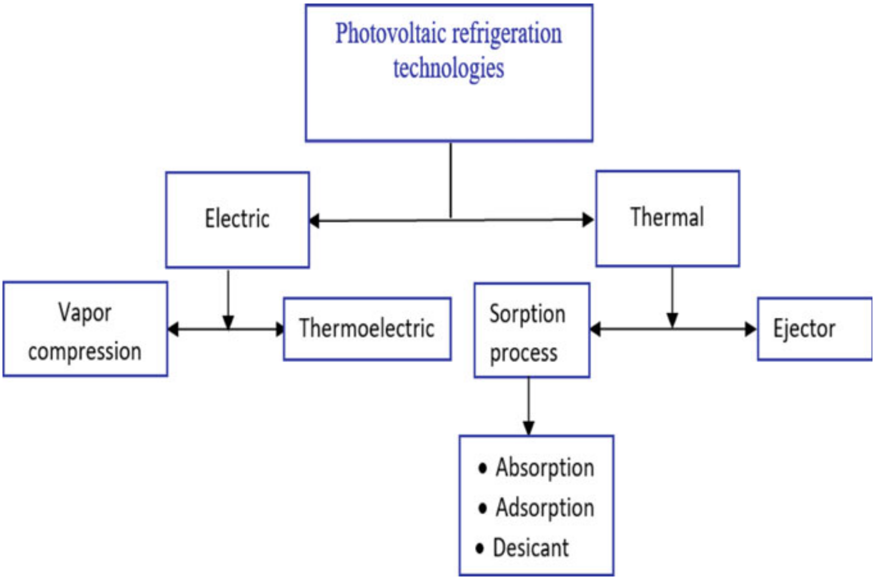


Fig. 20 Different cooling cycles incorporated with PV systems (Alsagri 2022)

The foregoing section showed the main cooling cycles, so solar cooling based on these processes has been pointed out.

2.3.1 Absorption Refrigeration

Because the solar absorption cooling cycle is classified as solar thermal refrigeration cycles, to supply the thermal energy needed for refrigeration, solar collectors, photovoltaic thermal collectors (PVT), and concentrating photovoltaic thermal collectors (CPVT) must be used (Maidment et al. 1999; Zhai et al. 2011). As pointed out in the literature absorption cooling was applied for vaccine storage. According to Siddiqui and Said (2015), the PVT is used in hybrid absorption processes such compression absorption refrigeration and ejector-absorption systems as well as absorption cooling cycles.

2.3.2 Adsorption Refrigeration

The process of adsorption, when using the right adsorbents, is comparable to that of absorption (Sah et al. 2015). Metal–organic frameworks (MOF) were examined by Rafique (2020) as promising adsorbents for solar cooling applications and it was discovered that the MOF might enhance the cooling cycle's efficiency. But the reduced COP makes this method less workable. Therefore, this system can be used for air conditioning and ice maker facilities as mentioned by (Dieng and Wang 2001).

2.3.3 Desiccant and Ejector Refrigeration

An experimental investigation on the dehumidifier and regenerator of a liquid desiccant cooling air conditioning system was carried out by Yin et al. in 2007. They emphasized that air conditioning is the primary use for desiccant cooling. Concerning thermal energy, ejector refrigeration is considered a low-grade technology, but because of its simplicity, the usage of this technology has become applicable. Several research works investigated the integration of ejectors with compression or absorption cycles (Braimakis 2021; Chen et al. 2013).

2.3.4 Vapor-Compression Refrigeration

One of the appliances that uses a substantial quantity of electricity is a refrigerator. Therefore, in order to lower greenhouse gas emissions and the price of PV systems, a decrease in energy consumption and efficient systems are crucial (Ekren et al. 2011; Mohammed et al. 2022).

PV systems as an alternative source of energy can be used to operate vapor-compression refrigeration. This application can be used for preserving vaccines, domestic refrigerators, icemakers, and cold storage. The combination of compression refrigeration with PV systems showed better economic potential compared to other solar refrigeration options (Ferreira and Kim 2014). In their review, they specifically examined thermodynamic and economic studies. Therefore, the significance of utilizing vapor compression refrigeration powered by PV can be seen.

Refrigeration in remote areas that away from the electricity grid need an off-grid power system. Solar energy (Photovoltaic) is considered an important power source for operating off-grid refrigeration. Recently, due to a reduction in PV system cost, therefore, solar-powered refrigerators have become more economical (Ayadi and Al-Dahidi 2019; Gao et al. 2018). During day time, the refrigeration system can be operated on PV modules but, the batteries are required to store extra energy during the daytime for usage at night (Li and Uckun 2016).

2.3.5 Solar PV-Powered Vapor Compression Refrigeration for Potato Storage

In order to create the ideal conditions for preserving potatoes, Eltawil and Samuel (2007a, b) conceived and constructed a solar PV-powered cooling system that use vapor compression refrigeration. The system had 490 W worth of PV panels, a lead-acid battery, and an inverter. Along with its primary parts, the vapor compression refrigeration system had a drier-cum-filter, an AC compressor, a condenser, an expansion device, an evaporator, an exhaust device, and evaporator fans. A cold storage structure with a capacity of 2.50 m^3 was built outside and properly insulated. Additionally, a storage structure with a capacity of 1.0 cubic meter, cooled by evaporation, was used for curing potato tubers. Figures 21, 22, 23, 24, 25 and 26 show the structural details of the constructed PV-powered cold store. The Kufri Chandermukhi variety of dried potatoes was kept in storage for five months. The performance of the designed system was evaluated. The potatoes' shelf life and the economics of the system were evaluated under different operating conditions. The potato tubers that had been stored were separated into two groups. The first group was used as a control and was allowed to sprout freely, while the second group underwent manual desprouting. The shelf life of the potato was determined by measuring the loss of moisture, dry matter, sprouting, rotting, sugar content, starch, and the quality of chipping.

The specifications of the vapor compression cooling system used in the experimental work are given in Table 2

The obtained results can be summarized as follows:

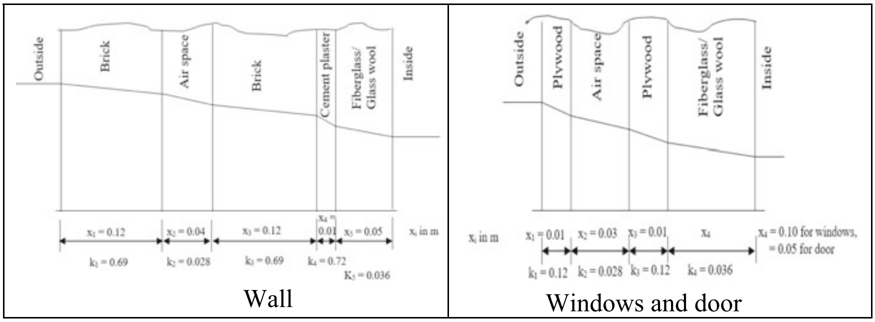


Fig. 21 Construction of the cold store's walls, windows, and door (Eltawil and Samuel 2007a)

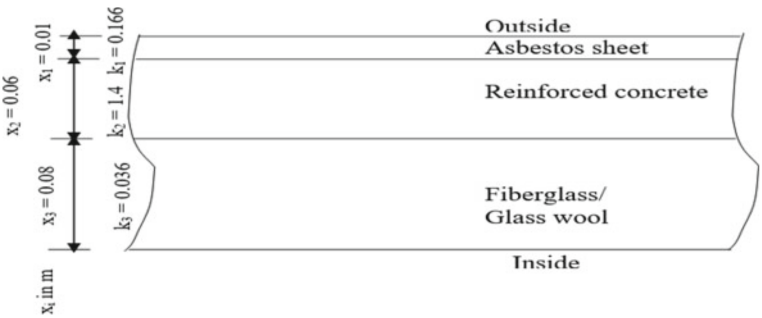


Fig. 22 Construction of ceiling (roof) (Eltawil and Samuel 2007a)

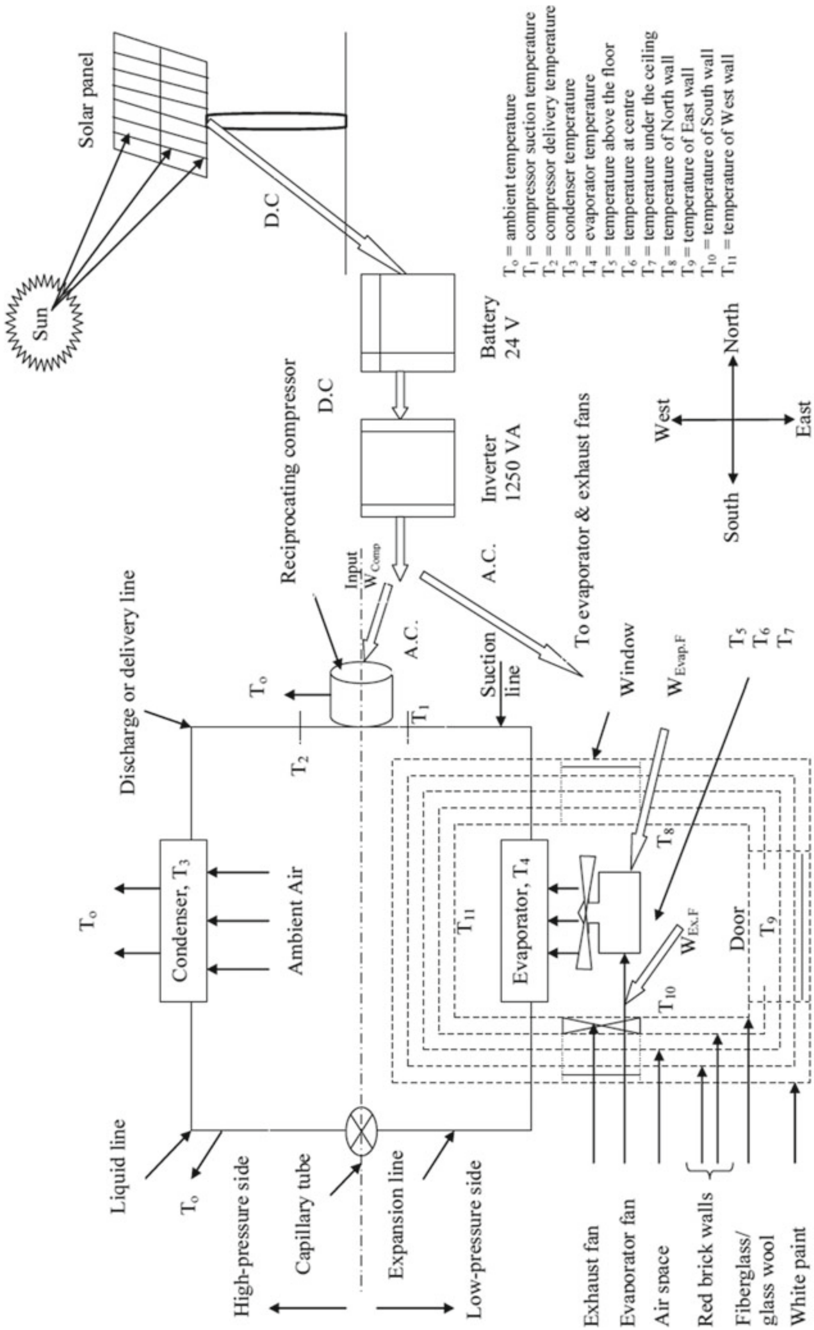


Fig. 23 Vapor compression cooling system for cold storage, schematic diagram driven by solar PV (Eltawil and Samuel 2007a)

Fig.24 Solar photovoltaic powered cold store (Eltawil and Samuel 2007b)

Fig.25 Curing of potato tubers using evaporatively cooled rice straw pad structure (Eltawil and Samuel 2007a)

- The average daily PV efficiency was about 11.73%, while the PV power output was 84.91 W.
- The average daily conversion efficiencies of PV modules were recorded as 8.90%, 7.77%, and 10.74% for module temperatures of 317.7 K, 318.3 K, and 299.1 K, respectively. These measurements were taken on clear sunny days during the summers of 2001 and 2002, and the winter of 2002.
- In order to charge the battery and run the cooling system over night, the solar panel supplied 490W of power. It was discovered that the energy supply from the panels decreased by 33.6% when the system was under full load. Additionally, it was determined that the output power was, on average, 26.53% higher than what the cooling system required when operating at full load.

Fig. 26 Inside view of cold store structure without load and loaded with cured potato tubers (Eltawil 2012)

Table 2 Specifications of vapor compression cooling system

Item	Specifications
Drier	Silica gel
Compressor	• Reciprocating sealed compressor, model number AE7 ZA7, 230 V, 1.4 A, 50 Hz, IP-LRA-9-R12 • 33.096 kN/m^2 is the suction pressure, while 1241.1 kN/m^2 is the discharge pressure
Condenser	• 24 tubes (18 main tubes + 6 secondary tubes), 17.90 m length, 0.3374 m^2 area • Fixed at 0.10 m behind the West wall (windward direction), ambient air is used for cooling the condenser
Evaporator	• 6 copper tubes of 1.0 cm dia, 0.2230 m^2 area, 7.10 m length
Chiller	• A chiller (tray) was kept under the evaporator to collect the condensed moisture from the air
Refrigerant	• A refrigerant of Freon-12 (250 ml) was utilized to serve at different operating temperatures
Expansion device	A 3.0 mm diameter capillary tube of 2.0 m length was connected to the evaporator exit tube in order to sub-cool the condensate
Thermostat	For controlling temperature, a mechanical type thermostat was used

- The cooling system, when operating at full capacity with stored goods and air-circulated cold storage, produced an average daily SPV power output of 5.60 kWh/d and had an energy consumption of 4.115 kWh/d.
- During the testing sunny days, the loaded and air-circulated cold storage structure's coefficient of performance (COP) varied from 2.83 to 3.62, with an average daily COP of 3.25.
- Taking into account various losses, the overall efficiency of the entire system was about 5.97%.
- For the conditions of empty and non-air circulated, empty and air circulated, and loaded and air circulated, respectively, the average temperatures inside the storage structures during the experiment were recorded as 285.39, 280.94, and 283.13 K, along with the corresponding inside relative humidities of 73.94, 81.21, and 86 percent.
- The overall expense of preserving and storing 1.0 kg of potatoes in a 2.5 cubic meter cold storage facility powered by a subsidized photovoltaic system, taking into account the 6% reduction in potato weight, is estimated to be 9.02 Rupees (1 US dollar = 46 Rupees). Conversely, if the system were operated using grid electricity (at 3.5 Rupees per kilowatt-hour) or a petrol-kerosene generator (at 10.47 Rupees per kilowatt-hour), the total costs per kilogram of potatoes would amount to 7.66 and 14.63 Rupees, respectively.
- The power output and temperature of the PV panel can be predicted using a number of multiple regression equations that have been developed. These equations can also forecast how much energy the cooling system would need and how well it will work.

3 Case Study in Saudi Arabia

3.1 Developed Solar Drying

Eltawil et al. (2018a, b) conducted a study on a solar tunnel drier (STD) that utilized a solar PV system to dry potato chips and peppermint. Figures 27 and 28 illustrate that the STD comprises a flat plate solar air collector and an axial DC fan, which were implemented to enhance thermal efficiency and maintain the drying chamber at an elevated temperature. The performance of the STD was assessed with and without a load, as well as with and without a thermal curtain placed on top of potato slices on sunny days. They investigated different levels of airflow rates (2.1, 3.12, and 4.18 m^3/min) and pre-treatments for potato slices. With an airflow velocity of 3.12 m3/min, the PV-powered STD was able to produce chips with a safe moisture level in 6 and 7 h, respectively, without and with the use of a thermal curtain. The frying time for potato chips was reduced to only 15 s. Using a black thermal curtain placed above the slices, 1% sodium meta-bisulfite produced the best chips in terms of color. Several thin-layer drying models were used to compare the predicted and

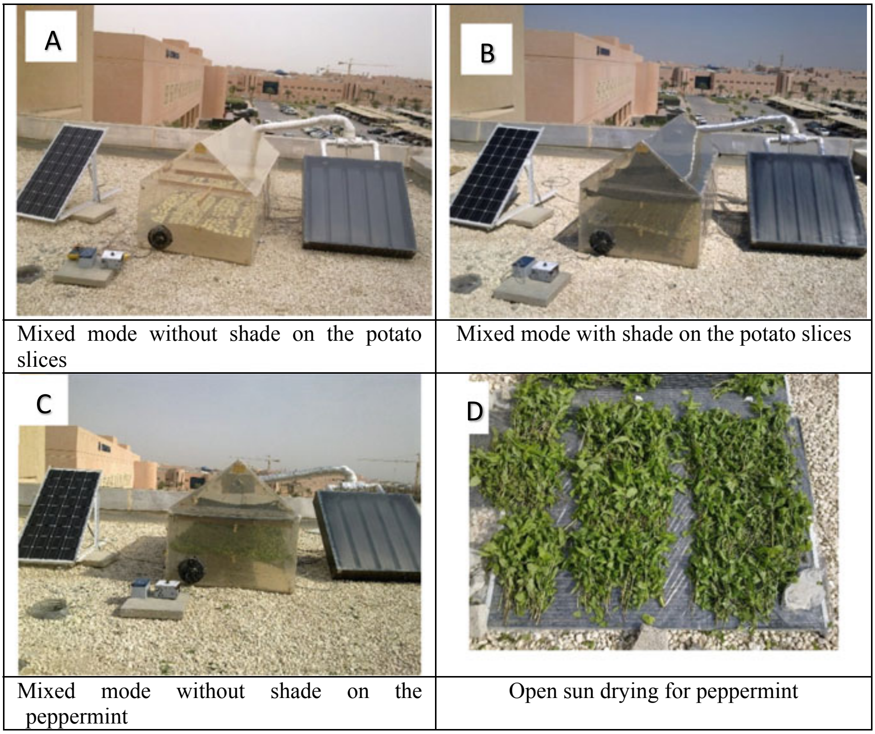


Fig. 27 The experimental setup involves a solar photovoltaic (PV) powered tunnel dryer designed for potato chips and peppermint. Two scenarios were tested: drying without shading and drying with a black thermal curtain on the product (Eltawil et al. 2018a, b)

experimental moisture ratios of chips using the developed STD. At an airflow of 0.0786 kg/s, the maximum drying efficiencies of 28.49 and 34.29% were achieved when a thermal curtain was not used.

Eltawil et al. (2018b) investigated a hybrid portable solar tunnel drier for drying peppermint using a flat plate solar collector and solar photovoltaic system, as shown in Figs. 28 and 29. The solar tunnel dryer can function in both direct and indirect thermal heating modes. A DC fan powered by the solar system runs in forced mode. A thermal curtain is also included to shade the mint and protect it from the sun's rays. The efficiency of the solar tunnel dryer was compared with open-air sun drying using one, two, or three layers of mint. Predicted and experimental moisture ratios of mint leaves dried in the solar tunnel drier were compared using several thin-layer drying models. The energy and environmental impacts of the hybrid solar tunnel dryer were also studied. The results indicated that the solar tunnel dryer took between 210 and 360 min to dry peppermint, whereas open-air sun drying took between 270 and 420 min. Among the models tested, the two-term model proved to be the most effective in simulating the thin-layer drying process of peppermint. The dryer efficiency, daily average photovoltaic efficiency, and total efficiency were 30.71%,

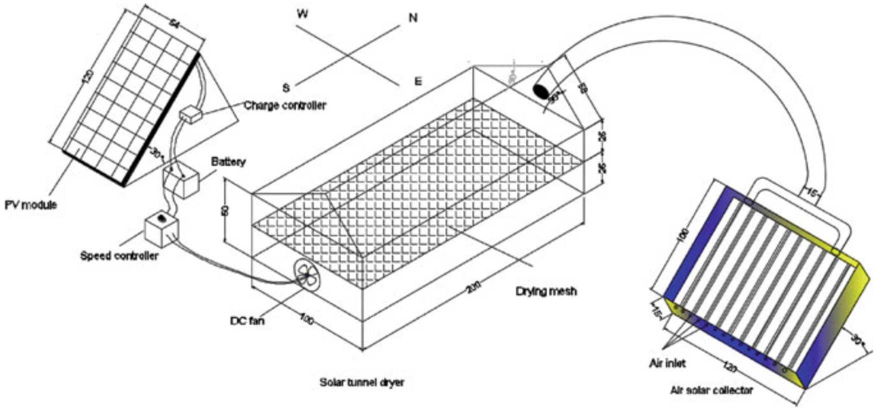


Fig. 28 The complete experimental setup's schematic diagram (Eltawil et al. 2018b)

9.38%, and 16.32%, respectively. The energy payback time was 2.06 years, and the lifetime net carbon dioxide (CO_2) mitigation was 31.80 tons. Peppermint dried in the solar tunnel dryer with a black thermal screen has better quality than peppermint dried in direct sunlight because it maintains its natural color and appearance. This technology is suitable for farmers and individuals living in distant locations without grid access. According to Eltawil et al. (2018b), drying peppermint using a black thermal curtain in a sun tunnel drier results in a higher standard of drying compared to drying it outside.

Azam et al. (2020) sought to create a standalone hybrid solar greenhouse dryer (GD) for small-scale tomato postharvest processors that incorporates a PV system and solar collector. To evaluate the thermal performance of the GD, which employs forced convection mixed-mode drying, the researchers used a mathematical model.

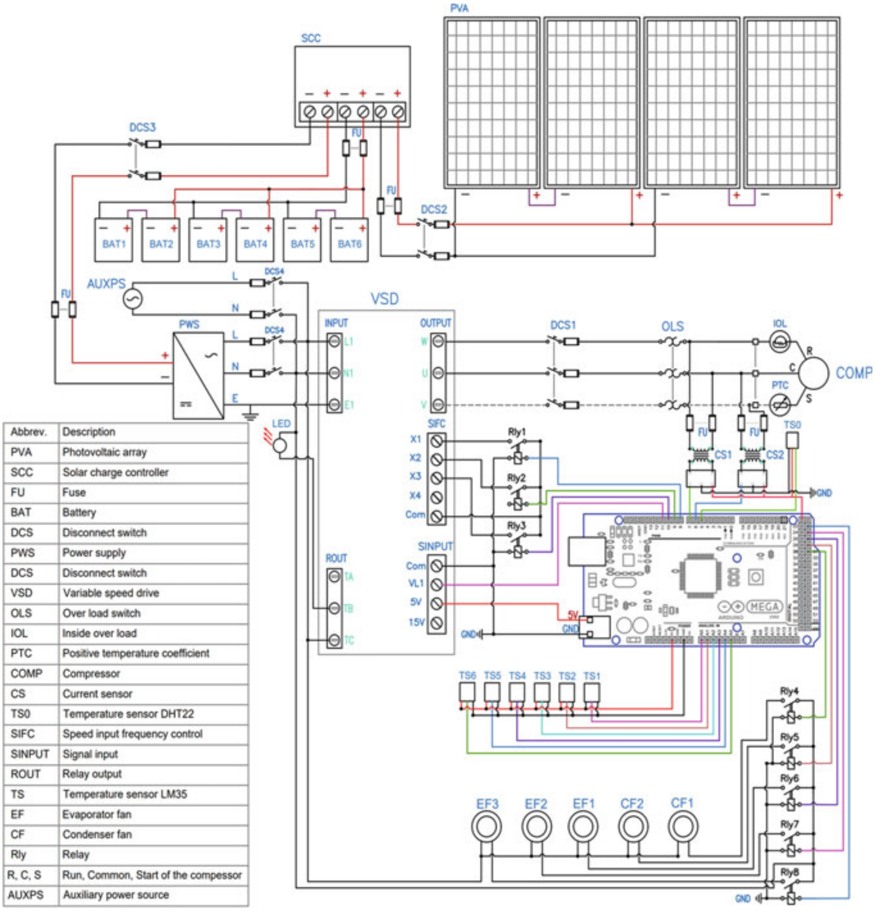
Fig. 29 Experimental setup of a solar PV-powered greenhouse dryer for drying tomatoes (Azam et al. 2020)

In order to find the best pretreatment and compare the final product's quality to open-air drying, they looked at a variety of pretreatments on fresh tomatoes, including full, half, and sliced, with and without blanching, and with and without sugar. The findings showed that compared to treatments without blanching, drying tomatoes in hot water for 15 min prior to drying resulted in a higher initial drying rate. According to the thermal energy analysis, the hybrid GD could capture useable heat gain from 6.45 to 26.62% of the solar energy that was available. The average daily heat gain dropped from 60 to 5% during the drying process. It was discovered that the hybrid GD's average total efficiency may reach 17.96% (refer to Fig. 29 for more details). Lastly, the technology is suitable for farmers without grid access, as it preserves the natural aspect and hue of the sun under shadowing.

3.2 Solar Display Refrigerator

Eltawil et al. (2023) developed and assessed an intelligent control system (ICS) for solar-powered display refrigerators (SPDRs) using machine learning and artificial neural networks (ANN). Figure 30 demonstrates the block diagram employed in the solar display refrigerator. while Fig. 31 shows the different components of the experimental setup. The refrigerator components and their specifications are summarized in Table 3. The SPDR was first run at a constant 60 Hz frequency. The proposed ICS combined with a variable speed drive based on ANN technology was then used to operate it at varied frequencies between 40 and 60 Hz. The necessary energy was provided by a standalone PV system. The performance of the developed SPDR was assessed and compared to its performance under a traditional control system (TCS) when operated at refrigeration temperatures of 1, 3, and 5 °C, which correspond to ambient temperatures of 23, 29, and 35 °C.

Figure 32 compares the SPDR with a modified ANN-based control system (MR) and the SPDR with a traditional control system (TR) in terms of their average daily power usage at a daily average temperature of around 29 °C and a product temperature of 3 °C. The Figure makes it clear that the MR uses less electricity than the TR and works the refrigeration system extremely smoothly. At average ambient temperatures of 23 °C, 29 °C, and 35 °C, respectively, the MR saved about 32.9, 33.4, and 35.5% more power when aiming for a product temperature of 5 °C than the TR. The solar PV system enables the operation of refrigerators in rural areas without relying on the electricity grid. The MR is expected to serve as the foundation for designing and optimizing PV-powered refrigeration systems. The results indicate that the power-modified control system (MCS) enhances the energy consumption and coefficient of performance (COP) of the SPDR. The ANN-based regression model is a more efficient and reliable control method that can be implemented in other refrigeration systems. To assess the effect of this improved solar-powered display refrigerator with the created ANN control system on the preservation of chilled fruits and vegetables, additional research is required.



Abbrev.	Description
PVA	Photovoltaic array
SCC	Solar charge controller
FU	Fuse
BAT	Battery
DCS	Disconnect switch
PWS	Power supply
DCS	Disconnect switch
VSD	Variable speed drive
OLS	Over load switch
IOL	Inside over load
PTC	Positive temperature coefficient
COMP	Compressor
CS	Current sensor
TS0	Temperature sensor DHT22
SIFC	Speed input frequency control
SINPUT	Signal input
ROUT	Relay output
TS	Temperature sensor LM35
EF	Evaporator fan
CF	Condenser fan
Rly	Relay
R, C, S	Run, Common, Start of the compressor
AUXPS	Auxiliary power source

Fig. 30 The solar-powered display refrigerator's block diagram (Eltawil et al. 2023)

3.3 Date Fruits Syrup (Dibs) Extraction Using Electro-Thermal Solar Energy

Dates are an important crop in the Kingdom of Saudi Arabia due to their high quality, which may not be available in other global markets. Dates possess nutritional value, including carbohydrates, proteins, and mineral elements. They also provide the human body with the necessary thermal energy, as they contain sugar, which can make up around 80% of ripe dates. (Aleid et al. 1999; Siddiq et al. 2014). Dates are among the crops that can be processed to produce some desirable products like dates dibs and dates paste.

Dibs (date syrup) is defined as "a concentrated diabetic liquid extracted from the fruits of some dates varieties, which is the aqueous and condensed extract by the heat

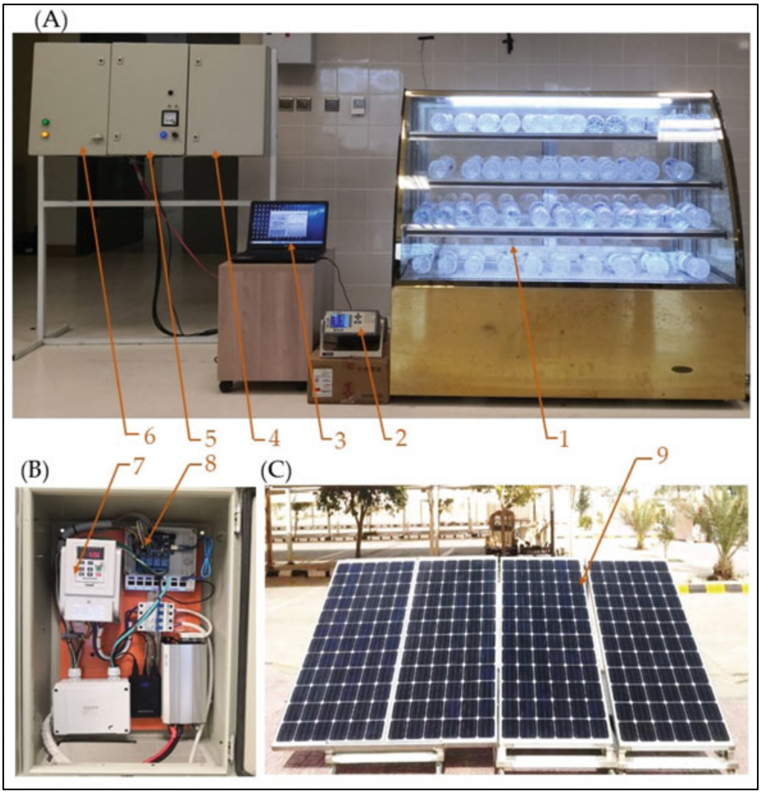


Fig. 31 Different components of the experimental setup. **A** The control panels and display refrigerator, **B** the operation control panel including inverter, **C** the solar PV array located outside the building. (1) The display refrigerator front view, (2) the multichannel temperature meter, (3) monitoring data using PC, (4) the frequency control panel, (5) the panel of electrical switches, (6) the panel of PV control, (7) variable frequency drive (VFD), (8) Arduino Mega and relay, and (9) PV modules (Eltawil et al. 2023)

of the natural contents of the fruit of the date, free of fiber, sediments, impurities, and foreign bodies, and is directly consumed or used in the manufacture of sweets and pastries" (Ibrahim 2014).

Some challenges or difficulties face the traditional method (TM) for dibs (Syrup) extraction such as long extraction period and low productivity. The insufficient presence of specialized factories and businesses has hindered the technological advancement of date conversion industries. The traditional method of dates syrup (Dibs) extraction is still in use, where it relies on heavy weights above the dates bags, and waits a long period until the extraction of syrup. Eltawil et al. (2021) designed a new electro-thermal solar energy method to extract date syrup. Two different methods of date syrup extraction were used and compared with the traditional one. In the traditional method (TM) the syrup was extracted by keeping the dates inside the

Table 3 Different specifications of the solar display refrigerator (Adapted from Eltawil et al. 2023)

Device/item	Number of units/specifications
Evaporator	• A copper tube with a 0.01 m diameter and 18.40 m length • The suction pressure as maximum value is 34.5 Pa
Evaporator fans	• Three fans (20 W power and 0.115 m diameter each), 220 V, and 0.12 A • The overall dimensions are 0.04 m in height × 0.12 m in width × 0.12 m in length
Condenser	Wire on the tube, there is a steel tube with a diameter of 0.01 m, a thickness of 0.001 m, and a length of 18 m
Condenser fans	Two fans, each measuring 0.25 m in diameter, with a power of 30 watts, operating on a voltage of 220 V and drawing a current of 0.19 amperes
Led light	Two LED lights, each with a power output of 20 watts
Capillary tube	The length of the copper is 3.49 m, with an outer diameter of 2.5 mm and an inner diameter of 1.0 mm
Drier cum filter	The diameter is 0.04 m and the length is 0.10 m
Compressor	• The text should be converted to proper English as follows: The model QB91C24GAX0 features a motor type RSIR (Resistance Start Induction Run) • A single phase, and maximum power output of 300 W at 220 V • A 9.07 cm^3 volumetric capacity and COP is 1.26 • An oil charge cooling system with a capacity of 250 cm^3 • The refrigerant is R134a, with a weight of 710 g • This model is manufactured by "Panasonic Industrial in Kuala Lumpur, Malaysia."
Cooling Cabinet of display refrigerator	• The dimensions of the cabinet are 1.50 m in length, 0.70 m in width at the bottom, 0.19 m in width at the top, and 1.37 m in height • 4 shelves. The main body of the cabinet, front, back, and side walls are also made from tempered vacuum-insulated glass 0.02 m thick • The overall heat transfer coefficient is 0.7 Watts per square meter Kelvin • The top and bottom of the cabinet are insulated with 30 mm of foam. The total effective capacity of the object is 0.580 cubic meters
PV Array	Maximum Power is 330 Watts, Open Circuit Voltage (Voc) is 45.9 V, Short-Circuit Current is 9.26 Amperes, Maximum Power Voltage is 37.3 V, Maximum current is 8.85 Amperes, power tolerance is 0 to positive 3 percent, and the dimensions are 1956 mm × 992 mm × 40 mm."
Charge controller	• The PC16-4015 A charge controller was utilized • The battery's nominal voltage was 12/24 VDC • The Voc of the PV system was about 145 VDC when operating at 24 V • The maximum input power from the PV system was 1200 W when operating at 24 V • The low-voltage protection point was set at 10.0 VDC/20.0 VDC. Consequently, the peak conversion efficiency reached an impressive 98%

(continued)

Table 3 (continued)

Device/item	Number of units/specifications
Batteries	• Six deep-cycle batteries (12 V, 200 Ah each) manufactured by Hefei Greensun Solar Energy Tech Co., Ltd., with the model FM250-12 were utilized • Two batteries were connected in series for each group, resulting in three groups in total. In order to achieve a final outlet string voltage of 24 V, which is connected to the inverter's input, the outlets of these three groups were then connected in parallel • The batteries' efficiency in charge and discharge is about 0.8. The daily energy use and required number of autonomous days can be used to calculate the energy storage capacity (ESC)
Solar inverter	• The MKS-3000 (3000 V-amps or 2400 W), a device made by Sunpal Power Co., Ltd. in Hefei, China, was used to convert the DC into AC which is required for refrigerator operation • The DC input is 24 V and 100 A, while the AC output is 230 VAC, 60 Hz, and 13 A • The maximum voltage from solar modules is 145 VDC
Control System	Phase 1: "Used a traditional control system that relied on a digital temperature controller (model 230 V, XR06CX, Dixell, Pieve d'Alpago, Italy) with a fixed compressor speed (FCS) set at 230 V/60 Hz" Phase 2: "Utilize an ANN-based control system (ANN-BCS) to regulate the variable compressor speed (VCS) and fan operation of the SPDR. The block diagram of the ANN-BCS and electrical circuit of the PV system can be found in Fig. 32. The control system, when integrated with the solar PV system, consisted of a PV array, charge controller, batteries, power supply, variable speed drive system, and control panel"

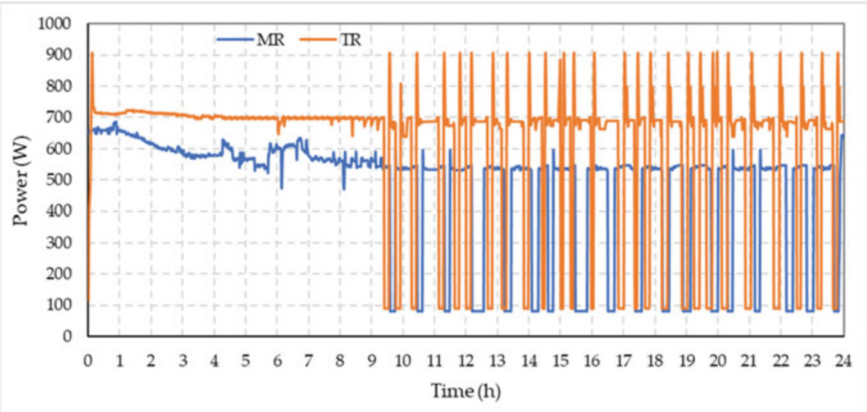


Fig.32 The solar display refrigerator (SPDR) with a modified ANN-based control system (MR) and the SPDR with a conventional control system (TR) were compared for their average daily power usage (Eltawil et al. 2023)

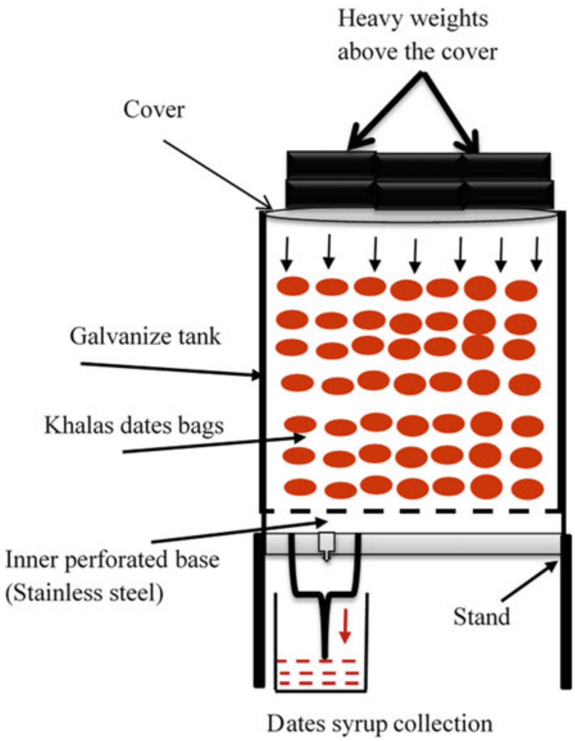


Fig. 33 Extraction of date syrup using the conventional (TM) method at room temperature

extraction tank and putting heavy weights above the cover of dates bags without any thermal treatment (at room temperature) as shown in Fig. 33.

Solar thermal energy was utilized to heat the syrup extraction medium, while solar electric energy was employed to operate and circulate the heating medium. Additionally, a manual hydraulic piston was employed to generate the required pressure (6 ± 1 and 7 ± 1 bar) to compress the dates, offering an alternative to the traditional method of using weights. Two solar heating methods were employed in the experimental setup, which consisted of a solar water collector or solar air collector along with a thermally insulated storage tank containing a rocky bed, a tank for extracting the syrup surrounded by a hot water jack or hot air jack, a water pump, and a PV system.

The first, was by heating with a solar water bath (Figs. 34 and 35), in which water was used as a medium for storing solar thermal energy. The second uses a solar air bath (Figs. 36 and 37) as a medium for heating with storing solar thermal energy in a rocks storage bed for use during the night. Furthermore, in both scenarios, the hydraulic piston was utilized for the process of squeezing the dates. The extraction process made use of solar thermal energy as a catalyst, which is not only renewable but also clean and environmentally friendly. To evaluate the developed heating methods, both methods were compared with the traditional extraction method used by farmers to produce date dibs.

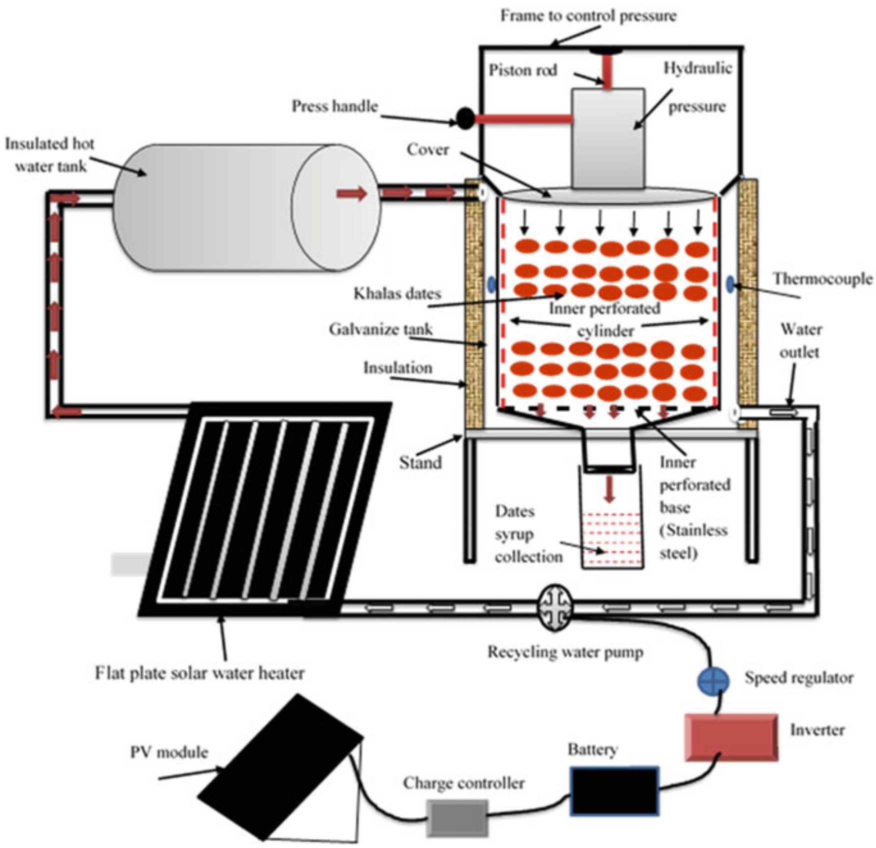


Fig. 34 Date syrup is extracted using a hybrid solar thermoelectric system (hydraulic pressure integrated with water bath heating)

The extraction tank was designed and manufactured from galvanized sheet and has a double-layer cylindrical shape (Fig. 38). The tank was isolated from the outside with foam. The space between the outer and inner diameter is utilized as a hot water bath or hot air bath to facilitate the process of extracting dibs (syrup). A cylindrical mesh basket, made of stainless steel, is placed inside the extraction tank to act as a filtering unit for the pressurized dates.

The extraction tank cover was made of heavy metal with a suitable diameter that allows it to move smoothly inside the cylindrical mesh up and down. The hydraulic jack was positioned above the tank cover and equipped with a handle to move the piston in the pressing direction, providing the necessary pressure (6 ± 1 and 7 ± 1 bar). The PV system comprises a PV module, charge controller, battery, and inverter. This system was used to supply the operational equipment with the required energy.

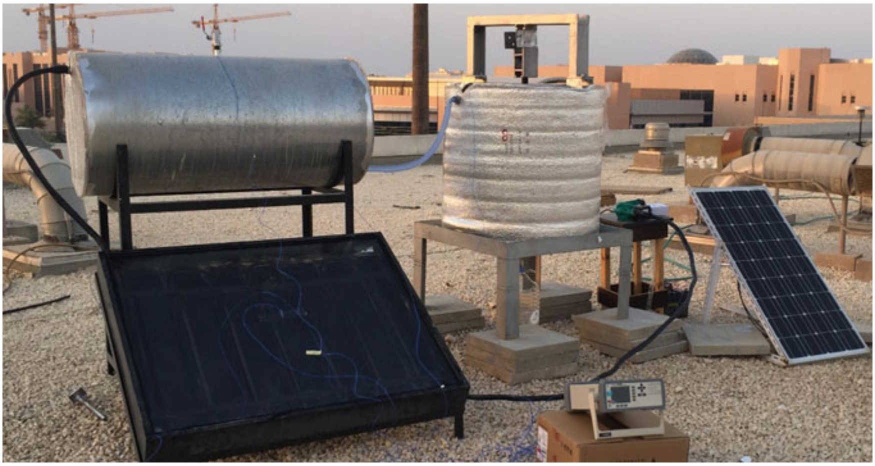


Fig.35 Hybrid solar thermoelectric system experimental configuration for making date syrup (water bath heating integrated hydraulic pressure)

3.3.1 The Extraction Process

1. Second-class Khalas dates were washed and sun-dried for about 3 hours, then packed and loaded into the extraction tank. Heavy weights were kept above the dates bags as in the traditional method (TM) while hydraulic pressure was used in the case of the electrothermal developed method
2. The water bath was filled with water that was heated using either a solar heater or hot air from a solar air collector and rocks storage bed.
3. It took around 10 hours for the dates in the extraction tank to warm up to a temperature of about 50 °C after being heated in a hot water bath (or hot air bath). The pressure started after that.
4. Two levels of hydraulic pressure (6 bar ± 1 and 7 bar ± 1) were employed for squeezing the dates. At first, the pressure was changed often; afterwards, it was changed every six hours in response to the pressure drop.
5. To maintain the temperature between 50 and 55 °C, the water in the water bath (or air in the air bath) was periodically circulated with the assistance of a control system.
6. Dibs extraction, also known as squeezing, continued until production ceased or decreased.
7. Daily collections of the created dibs were made, and they were kept in the refrigerator at a temperature of 4–5 °C. After then, samples were gathered to assess the production's dibs' quality.

The outcomes can be summarised as follows:

- The average daily PV efficiency was about 11.73%, while the PV power output was 84.91 W.

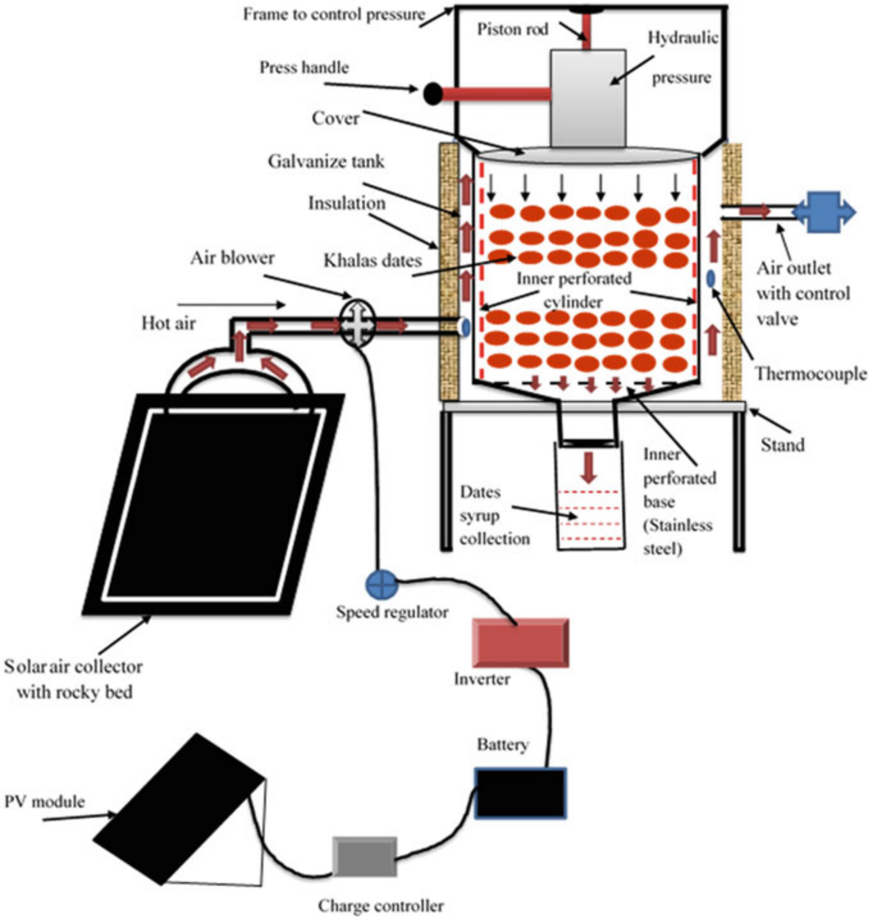


Fig.36 Using a hybrid solar thermoelectric system to make date syrup (thermal rocky bed- Air bath integrated with hydraulic pressure)

- The average power consumption of the water pump was 44.02 W while the power consumption of the air pump was 53 W.
- For the developed dates extraction systems, the temperature inside the compressed dates varied from 49° to 54°.
- The efficiency of heating dibs extraction medium using a solar water bath was 48.87%. In contrast, with a solar air bath, it was approximately 13.16%. Consequently, using a water bath is recommended.
- The developed systems shortened the extraction process period and saved approximately 38% of the time compared to the traditional method.
- In the case of water bath heating, the syrup productivity increased by approximately 28.75% and 36.66% at a pressure of 6 ± 1 and 7 ± 1 bar, respectively.

Fig.37 Solar thermoelectric system experimental setup for making date syrup (Air bath with a thermal rocky bed integrated with hydraulic pressure)

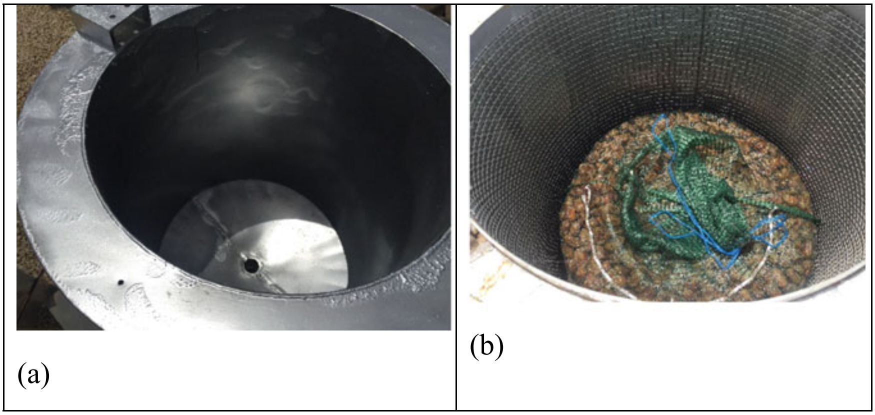


Fig.38 Dates syrup extraction tank. **a** Empty tank surrounded by the thermal bath, **b** The tank filled with perforated cylinder (extraction mesh) and some dates before squeezing

- In the case of air bath heating, the productivity was improved by 24.27% and 29.31% at a pressure of 6 ± 1 and 7 ± 1 bar, respectively.
- Increasing the squeezing pressure under the same thermal treatment led to an increase in productivity.
- The moisture content of dibs ranged from 12.8 to 13.9% (dry basis).

- The sugar content for the traditional method was 82.5%, while it ranged from 79.7 to 81.5% at a pressure of 6 bar ± 1 and from 78.9 to 82.3% at a pressure of 7 bar ± 1 in the case of heating with the water bath.
- The findings demonstrated that all procedures and treatments yielded dibs (syrup) with good color, ranging from red to yellow.
- A new method that makes use of renewable energy sources and yields high-quality date syrup is offered by the developed solar electro-thermal energy system in combination with hydraulic pressure for the extraction of date dibs, which is beneficial for remote areas.

4 Recommendations for Future Research

- Using the PV system on-grid/off-grid is advised for large-scale cold storage.
- Using both the PV system and a smart IoT-based control system is recommended for remote management of cold storage facilities.
- It is recommended to use the integration of PV systems and machine learning/ artificial intelligence for smart farming.
- It is recommended to use solar greenhouses and IoT for precision farming and verticle farming (hydroponic and soilless cultivation)
- It is recommended to use machine learning and intelligent control system for enhancing the refrigerators' performance and saving energy.
- Applying a thin film roof water flow over the external cover of a greenhouse operated under the fan-pad system can lead to an additional reduction in temperature with considerable energy consumption and costs.
- Soil-less cultivation makes it possible to produce, with only little water consumption and a small amount of physical work but with great dedication and constancy, fresh and healthy vegetables in small spaces. Also this technique gives promises to solve land shrinking in cities out of cultivated lands and without increasing costs.
- Because of a lack of water, the salty or wastewater can be utilized for irrigation using a straightforward method involving solar stills that can be installed in furrows between ridges. Implementing solar stills for irrigation can help mitigate erosion caused by irrigation and decrease the amount of water needed for irrigation, while also allowing for the reuse of waste or salty water.
- To generate the necessary pressure for dibs extraction, it is advised to employ solar energy to run a fully automated hydraulic compression system. Also, to maximize syrup productivity the seedless dates (without inside kernel) should be used.

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Chapter 13
Agricultural Extension Implication on Food Security in Saudi Arabia

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Abstract Agricultural extension is a crucial component in promoting the progress of rural communities and the agricultural sector at large. It plays a crucial role in enhancing the productivity of various crops, which in turn, helps reduce the food gap in societies. Developing countries rely heavily on agricultural extension to improve their agricultural sector, as it often struggles in comparison to developed countries. To achieve food security in the Kingdom of Saudi Arabia, the agricultural extension sector and its workers must make more efforts to contribute to agricultural development and reduce the food gap. This chapter provides a more detailed explanation of the concept, philosophy, and goals of agricultural extension, specifically highlighting the connection between agricultural extension and food security. Specifically, it analyses the dissemination and adoption of agricultural innovations, sources of agricultural extension information, agricultural extension campaigns, expert agricultural systems, and the privatization of agricultural extension, and how these impact food security in agricultural communities. The importance of agricultural extension appears in the development of the agricultural and rural sectors. The Kingdom of Saudi Arabia has a clear plan that seeks to provide extension services through the General Administration of Agricultural Extension and activate cooperation with governmental and private agricultural institutions to contribute to the advancement of the agricultural sector and contribute to achieving food security.

Keywords Adoption · Agricultural innovation · Diffusion · E-extension · Expert systems · Extension privatization · Food security · Saudi GAP

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1 Introduction

Agriculture serves as the primary means of livelihood for approximately two-thirds of sub-Saharan Africa's population. Thus, enhancing agricultural development through effective extension services is essential in ensuring food security in such nations (Elias et al. 2013; Abdu-Raheem and Worth 2011). The world's population gets its food from the agricultural sectors. Agriculture also provides raw materials for many industries, like the textile and food industries. It's important to mention that advancements in the fundamental sectors of countries, such as health, education, and modern technologies, can impact consumer behavior. This can be accompanied by population growth, leading to a higher demand for various high-quality agricultural products that meet their food needs in terms of quantity and quality. Therefore, the agricultural sector must adapt and develop to meet such demands by providing agricultural education, research, and modern technology promptly and effectively to farmers through efficient agricultural extension services. For example, in Somalia, small and large farmers receive agricultural extension services focusing on agricultural inputs and farmer institutions to enhance crop quality and provide better marketing opportunities (Maow and Temizel 2021). It is crucial for agricultural extension services to address regional natural systems' specificities for producing efficient and sustainable agricultural crop plans, resulting in the high efficiency required to accomplish food security (Francis 1990).

2 Concepts of Agricultural Extension

Agricultural extension is reliant on methods of adult education as its primary objective is to provide assistance to farmers, their families, and their environment. Its purpose is to enable them to make use of the resources available to them through their own efforts, improve their skills, knowledge, and attitudes, and ultimately increase their economic and social level by promoting favorable behavior. Due to the technological revolution and the impact of the Corona pandemic, digital extension platforms, as well as communication links between extension, agricultural education, and agricultural research, such as the VERCON and RADCON expert systems have been introduced by the FAO to make up for the shortage of qualified counselors and the consequent decline in extension services. This decline has been exacerbated by the impact of the Corona pandemic and the continuous shortage of counselors. The Corona pandemic has had detrimental effects on all sectors, including agricultural extension services. This pandemic has imposed restrictions on the movement of extension service providers to reach beneficiaries (Atwongyeire 2022). In 1873, the term extension education originated in England as a means of expanding the activity of universities to serve the surrounding community. The goal was to develop extension programs that meet the needs of farmers in a timely manner. The concept of extension work was based on agricultural education, the adoption of agricultural innovations, and meeting the needs of the target agricultural audience. Efforts to implement this concept continued worldwide, both in developed and developing countries. The definition of agricultural extension varied depending on the multiplicity and diversity of societies and specialists in each country, as well as the goal of its application and the extent to which it can be achieved.

Various scholars have offered their own definitions of agricultural extension. Researchers see it as a system that promotes profit-focused agriculture and aims to enhance rural life. Kesley and Hearne (1966) perceive it as a non-school educational tool that supports adults and youth with problem-solving. Leagans (1963) describes it as a process of introducing new ideas to rural individuals while encouraging their implementation. Additionally, Arab scholars specializing in extension have contributed to the definition. Numair (1983) defines agricultural extension as a non-school educational service that trains and influences farmers and their families to adopt innovative agricultural methods and ideas. Abdel-Ghaffar (1976) portrays it as a collaborative and adaptable educational process guided by an extension organization that invests in farmers' motivations and provides valuable information to achieve efficient resource utilization and future development. The ultimate objective is to bring about a change in farmers' attitudes and behaviors, leading to the well-being of rural people, their society, and their country (Omar et al. 1973; Swailem 1998).

According to Ijatuyi et al. (2017) and Ismail (1995), agricultural extension involves providing farmers with knowledge and skills in modern agricultural technologies to enhance agricultural production, farmers' income, and quality of life. The delivery method used is participatory, allowing farmers to access information and technologies for innovating and developing skills. The agricultural extension also helps strengthen connections between farmer-based organizations and related entities, aiming to provide small farmers with the necessary information and skills. One of the most comprehensive definitions of agricultural extension is provided by Omar and his colleagues, who define it as non-school education carried out by an integrated body of professionals and local leaders to serve farmers and their families. The goal is to help farmers improve their economic and social level by bringing about desirable behavioral changes in their knowledge, skills, and attitudes. Agricultural extension focuses on informal education, mainly aiming to develop and advance farmers to improve their standard of living. It is carried out by an independent professional body of guides and local leaders and provided to adults from the rural population, including farmers, youth, and rural women. It is more applied fieldwork than academic scientific work and depends on coordination and integration between the fields of applied, specialized, and research agricultural rationalization. It emanates from the urgent needs and concerns of farmers to ensure their acceptance of it and their positive participation in its activities. Agricultural extension does not focus on providing aid or financial incentives to farmers but rather provides an educational extension service that helps farmers achieve their goals by improving their skills to benefit from some agricultural practices. This increases agricultural production in both its plant and animal parts with high quality, and then increases their incomes and improves their standard of living. The proverb, "He who taught me to fish is better than he who gave me fish," applies to this situation, as teaching new skills can benefit farmers more in the long term than providing temporary aid.

Unless individuals improve their behavior by increasing their knowledge in areas related to their work, positive changes will not happen. However, mere knowledge alone is not enough. The critical factor is how to transform that knowledge into action, which requires enhancing both mental and motor skills. This ability will allow individuals to benefit from what they have learned. For farmers, this means developing positive attitudes, interests, and inclinations towards agricultural ideas and easing negative sentiments towards both those ideas and agricultural extension in general. The role of agricultural extension is not only limited to the teaching process. It goes beyond that, as it requires a unique type of educational material that needs to be handled with great specificity to ensure agricultural development is achieved. This is accomplished by encouraging farmers to change their behavior and accept agricultural innovations in order to meet the needs of farmers at all educational and social levels. Content must be produced accordingly. Successful extension education must take into account the issues that farmers face and prioritize them accordingly, seeking technical solutions that simplify and clarify the information so that the farmers can more easily understand and apply it. Ultimately, the goal of agricultural extension education is to empower farmers to solve their problems leveraging their own capabilities and knowledge.

3 Objectives of Agricultural Extension

The objectives of agricultural extension involve introducing innovative agricultural methods and ideas to farmers, encouraging sustainable production patterns and the use of improved tools, and advocating for good agricultural practices that align with the socioeconomic status of farmers (Ahmad et al. 2007). In the past, agricultural extension was largely implemented through training programs and field visits (Ragasa and Mazunda 2018). While the organizing of agricultural extension agencies may vary across countries, there are general objectives that can be achieved, including modernizing rural communities, raising the standard of living of the rural population, increasing agricultural productivity efficiency, and integrating agricultural activities with other related sectors. The objectives of agricultural extension consist of three levels, starting with national objectives and ending with educational objectives. The fundamental objectives are considered the basic objectives for society and involve teaching farmers to identify their problems and apply new knowledge to achieve a more prosperous life. The general objectives are directly related to agricultural extension and focus on specific economic, social, health, recreational, and educational aspects of farming. Working objectives are specific objectives that address individual and group needs and contribute to the achievement of the general objectives. The general objectives of agricultural extension aim to bring about desirable behavioral changes in farmers' attitudes, knowledge, and skills, such as feeding young livestock on non-traditional fodder or preserving agricultural lands from deterioration (Ismail et al. 2009).

4 The Philosophy of Agricultural Extension

The philosophy of agricultural extension consists of a set of principles that distinguish it from other educational activities. These principles justify agricultural extension as a vital developmental activity that significantly impacts the improvement of rural communities, leading to greater food security. Some of the principles include the fact that agricultural extension is an educational activity, belief in human capacity, belief in natural human gatherings, and the generality of extension services. Agricultural extension is considered a form of adult education that helps achieve the goals of the country's educational system. Agricultural extension workers are regarded as agents of change for farmers. The belief in human ability recognizes that only humans can develop and create things to improve their lives and society. Human beings prefer to live in groups and have certain rights and responsibilities towards society, including the responsibility to help themselves. The success of agricultural extension depends on the ability of extension workers to guide farmers and convince them to apply technical recommendations and agricultural innovations, rather than forcing them to do so.

The principle of the generality of extension services highlights the importance of providing these services to all farmers, without discrimination based on origin, gender, religion, or locality. In addition to these four principles, several rules distinguish agricultural extension from other educational activities. These rules help to provide more effective agricultural extension services and contribute to improving the quantity and quality of agricultural products. Some of the rules include implementing extension services based on the current level of farmers in terms of their education and skills; teaching farmers how to think for themselves, relying upon farmers' own resources; planning programs based on local conditions and needs; strengthening relationships between extension authorities and local agencies; and coordinating efforts between agricultural extension, education institutions (agricultural education), and scientific research centers (agricultural research). In addition to controlling the effects of them on food security (Fig. 1).

5 Agricultural Extension and Food Security Linkage

Agricultural extension and its link to food security is critical in achieving adequate food production in the face of population growth, limited agricultural resources, and climate change. To achieve vertical expansion in food production, farmers must adopt the latest agricultural technologies. Access to agricultural extension services has

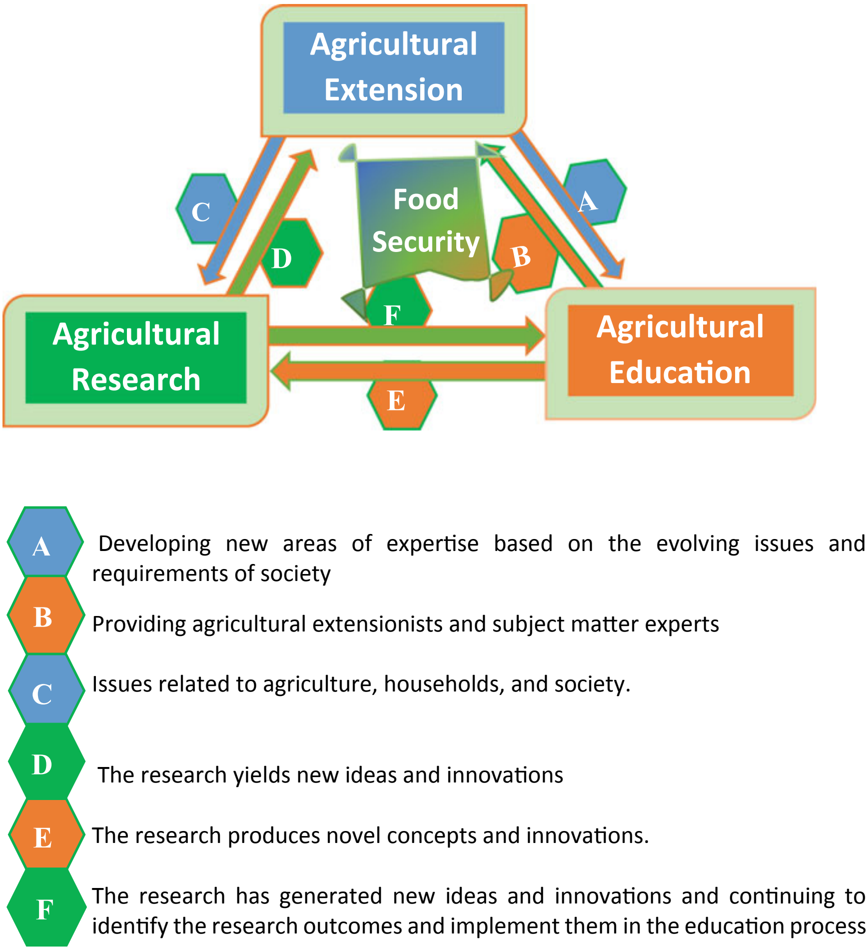

Fig. 1 The integrated relationship between agricultural education, scientific research, agricultural extension, and food security. *Source* Ismail et al. (2009)

enabled farmers to increase their food production. The Food and Agriculture Organization of the United Nations (1996) defines food security as the state in which all people have the physical, social, and economic capabilities to obtain sufficient, safe, and nutritious food to lead active and healthy lives. Food security can be classified into absolute and relative food security, where the former refers to self-sufficiency in food products within the country and the latter refers to the state's ability to provide food products partially or wholly by importing from other countries. The need to develop the agricultural sector in Saudi Arabia is essential to reduce the import bill and its impact on the national economy due to high population growth rates. Food security is a broad and comprehensive concept as most countries seek to achieve food security for their people, which positively affects their political, social, and economic stability. Food, water, and environmental security are essential components of national security. Agricultural extension is vital in enhancing food security by raising the knowledge capabilities of farmers and providing them with agricultural expansion services. The agricultural extension can significantly contribute to the four main pillars of food security, namely, availability, accessibility, utilization of food, and food stability. Achieving sustainable agricultural development is critical in bridging the gap between food production and demand. Agricultural extension plays an essential role in developing agricultural production by promoting the quality and quantity of clean and organic agricultural products and improving people's health. The productivity of agricultural crops and farms' efficiency increases through the effectiveness of agricultural extension agencies. Agricultural extension is vital in the lives of rural families in areas dependent on agricultural activity through increasing their income levels and standard of living. Various agricultural extension programs and activities increase small farmers' role in achieving food security by developing production methods used in their farms. The use of modern irrigation systems, reducing water and energy consumption, and achieving environmental sustainability are crucial in reducing energy consumption in the agricultural sector. Scientific studies have indicated a significant decrease in irrigation water and fuel efficiency in farms in various regions of the Kingdom, requiring greater extension efforts to educate farmers on using advanced technologies.

5.1 Diffusion and Adoption of Agricultural Innovation and Implications on Food Security

Agricultural extension plays a vital role in attaining food security, which ultimately helps in reducing poverty. To achieve food security, it is crucial to ensure the sustainability of food systems and supply chains at all stages. In light of this, numerous countries have embraced the policy of economic liberalization, recognizing its contribution in improving agricultural productivity. This policy necessitates farmers to adopt modern agricultural technologies, enhance the effectiveness of resource utilization, and actively seek research products pertaining to the agricultural sector and its supporting industries. These actions collectively work towards increasing production, and efficiency, and ultimately achieving food security. Despite this, some farmers remain hesitant to adopt these technologies, weakening food security. Thus, agricultural extension efforts are necessary to increase the adoption rate of modern technologies and innovations among agricultural producers (Ayinde et al. 2013). To achieve diffusion of agricultural innovations that enhance farmers' knowledge and skills, thus increasing productivity efficiency, working with small groups of farmers is recommended. Ensuring their interaction with extension staff and facilitation of communication between farmers will promote the adoption of agricultural innovations or good agricultural practices. Extension workers play a critical role in persuading farmers to implement recommended agricultural ideas.

The adoption process can help achieve food security through increased food crops productivity, enhanced preservation and storage methods, reduced food loss, and an increased period of agricultural products in markets. Increasing the utilization of advanced agricultural innovations is the cornerstone for transforming traditional agriculture into modern agriculture. Adopting the latest agricultural technologies by small farmers to optimize resource use, irrigation water, and increase crop productivity and financial return is key to achieving this transformation. Agricultural extension agencies must play a pivotal role in technology adoption and knowledge transfer, which constitutes the main focus of agricultural extension work. In Africa, the agricultural sector's digitization has sparked many smart applications based on mobile phones. These applications aim to provide agricultural extension and advisory services, along with market, finance, and food supply chain information. A report entitled "Digitalization of African Agriculture" (CTA 2019) noted that 33 million small farmers used these applications in 2019, with expectations of 200 million farmers using digital services by 2030 (Ayim et al. 2022). In Saudi Arabia, modernizing and developing the agricultural sector hinges on widespread diffusion and adoption of agricultural innovations among farmers. Modern technologies can contribute to increased productivity of agricultural products, enhance farmers' connectivity, increase access to accurate and timely agriculture information, improve agricultural value chain efficiency, and enhance climate change resilience (Ayim et al. 2022). The Ministry of Environment, Water, and Agriculture (MEWA) (2023) launched the "Agricultural Guide" application on smart devices, enabling farmers and investors to request that the region's agricultural extension agents visit their farms to evaluate any problems they face and provide solutions. The application facilitates communication between agricultural specialists and extension agents, allowing farmers to inquire about obstacles they face. Since its launch, the application has provided over 2.9 million agricultural consultations. The MEWA seeks to automate the agricultural sector, making it easier for farmers and enhancing the efficiency of their farms and contributing to achieving food security. Through employing innovative and flexible models, processes, and operations, MEWA aims to achieve the goals of Vision 2030 by investing in smart technologies.

5.1.1 Categories of Adopters

The process of adopting agricultural innovations involves a mental process that farmers go through, from the initial concept or technology being introduced to them, to it becoming a part of their daily practices. Throughout this process, beneficiaries are expected to go through the various stages of the innovation-diffusion model, which include awareness, interest, evaluation, experimentation, and adoption. As per this model, the adopters of innovations fall into five distinct categories: innovators, early adopters, early majority, late majority, and laggards. These categories are based on the date of adoption, and are illustrated in the Innovation Adoption Curve, as proposed by Rogers (1995) (Fig. 2).

Fig. 2 Innovation adoption curve. *Source* https://cwbsa.com/innovation-adoption-curve

Each category of adopters has similar characteristics and distinct sources from which they obtain necessary information for the adoption process. The Innovators are mostly large-scale farmers who are adventurous in trialing and adopting innovations. They have the ability to understand and apply complex ideas and experiences and bear the financial risks resulting from their application. The second category is the Early Adopters. Compared to the Innovators, they are more integrated into their social systems but less open to the outside world. They have a higher degree of leadership in public opinion. Individuals in this category are considered experts who can be referred to before experimenting and adopting innovations. They are relied upon by agricultural extension workers to help in advancing the process of disseminating new ideas or experiences at the local level. The third category is the Early Majority. The members of this category adopt innovations on a large scale, depending on the extent of their application by the Early Adopters. Their decisions depend on utility and practical benefits. The fourth category is the Late Majority. They adopt new ideas on the basis of economic needs and societal pressures. They often adopt new ideas after most individuals in society have already adopted them. Their adoption of these ideas takes place after making sure that they are acceptable in society and compatible with customs, traditions, behavioral, and productive patterns. The last category is the Laggards. They are the last to think of adopting innovations and new ideas. Members of this category are characterized by being closed in on themselves, largely isolated from the outside world, and greatly affected by the past and its experiences. Their decisions are affected by what has been inherited from previous generations, and they are more interactive with traditional farmers.

5.1.2 Factors Affecting the Rate of Adoption

Most of the literature on diffusion and adoption has found that the rate and level of adoption are determined by the actual benefits that potential adopters receive (Amir and David 1999). The rate at which farmers adopt agricultural innovations is relative to the rate at which farmers in a particular community adopt that innovation. It is estimated by calculating the percentage of farmers who adopted the idea compared to the total number of targeted farmers who know about the innovation during a specific period. There are several factors affecting the rate of adoption of any idea or innovation in any society, as shown in Fig. 3 (Ismail et al. 2009).

It should be noted that there are various factors that contribute to the success of an innovative idea, including its comparative advantage, compatibility with societal values, complexity, ability to be experimented and fragmented, and clarity of results. Nowadays, the diffusion of new ideas has been facilitated by the availability of mass communication such as television, radio, social media, and agricultural e-extension applications. This is particularly effective in introducing farmers to new ideas. Additionally, the education level of a society's farmers plays a significant role in the speed at which they adopt new technologies, with educated farmers adopting quicker than their illiterate counterparts. Similarly, farmers with large farms tend to adopt modern technologies faster than those who do not. There are several factors that determine the success of agricultural extension efforts. It is important to train and develop extension workers, improve their communication skills, and ensure they have good personal characteristics and practical experiences in order to increase the adoption rate of new agricultural innovations. Ultimately, the decision to accept a new idea is made by the farmer either independently or with the influence of a group

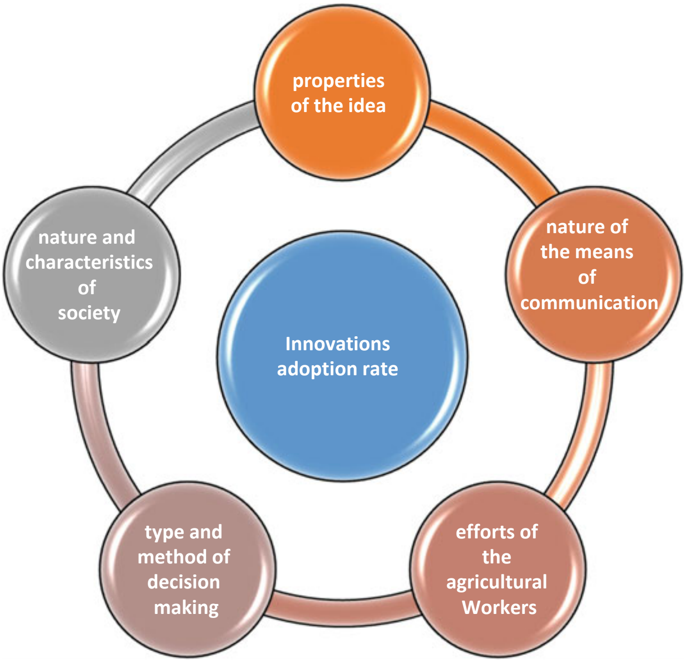

Fig. 3 Factors affecting the innovation adoption rate. *Source* Created by the authors

of farmers. Individual decisions lead to faster adoption rates, while collective decisions take longer. Binding decisions issued by competent authorities can also lead to faster adoption rates.

5.2 Sources of Agricultural Information

Agricultural information is vital in enhancing farmers' knowledge, practical skills, and attitudes towards adopting innovative ideas and agricultural practices. Nonetheless, farmers face a variety of obstacles and constraints when trying to access this type of information. According to Odini (2014) study, which aimed to evaluate small farmers' access to agricultural information and their usage to achieve food security in Kenya, current agricultural information systems fall short in meeting the needs of small farmers due to their inefficient infrastructure and lack of necessary technical competence. Similarly, a study regarding the dissemination of agricultural information and its impact on food security in Zimbabwe revealed farmers' needs for information about crops, livestock, fertilizer, pesticide usage, and modern farming techniques. The study demonstrated that the most important sources of agricultural information were radio, posters, and agricultural extensionists. However, this study also revealed that the most significant obstacles to obtaining agricultural information lay in the discrepancy between the broadcasting times of agricultural information via radio and the times when farmers are occupied with farming operations, high illiteracy rates, low awareness of the importance of agricultural information sources, inadequate numbers, and underqualified agricultural extensionists (Fiskani and Felix 2018). In the same direction, it was found that low income of farmers, lack of sources of agricultural financing, and high costs of production inputs negatively impacted access to agricultural information sources, notably amongst rural women farmers. It is, therefore, paramount for agricultural extension services to rely on adult education programs to enhance rural women's access, and utilization of agricultural information sources. This highlights the need to expand agricultural extension packages, particularly those meant for rural women in targeted areas (Abanyam et al. 2023). These findings align with the classification of agricultural information sources developed by Ismail and others (2009), where agricultural innovations are typically discovered and produced by universities, scientific research centers, and progressive farmers. Agricultural extension workers transfer these agricultural innovations to end-users. They have a position to evaluate and control innovations and may suggest viable ideas that farmers can implement. The sources of these innovations and information could be individuals or specialized agricultural organizations and can be categorized as follows.

5.2.1 Agricultural Authorities

Agricultural Authorities consist of agricultural agencies, agricultural extension training centers, and cooperative societies. These entities or organizations can be found at both national and local levels.

5.2.2 Personal Sources

This category encompasses all individuals, both farming and non-farming, that farmers resort to in order to obtain or receive agricultural information. This includes agricultural cooperative employees, agricultural extensionists, family members, other farmers (such as relatives, friends, and neighbors), as well as non-farmers, such as teachers or owners of crafts or other professions. These personal information resources are of great importance, especially when farmers are determining whether or not to adopt new innovations or ideas.

5.2.3 Mass and Social Media Sources

Mass and social media sources include radio, television, agricultural magazines, newspapers, Facebook, Instagram, and agricultural applications. These sources are particularly useful for providing initial information about new ideas and innovations.

5.2.4 Commercial Sources

Commercial agricultural organizations are primarily focused on selling production inputs to farmers and buying their agricultural products. As a result, these organizations are highly invested in providing up-to-date information about agricultural inputs and processes that can improve the quality of agricultural production. They also provide after-sales services to farmers, especially when purchasing agricultural machinery.

5.3 Agricultural Extension Campaigns (AECs)

AECs have a significant impact on disseminating agricultural information and innovative ideas among farmers, thereby raising their technical capabilities and achieving food security. A carefully designed plan is necessary to disseminate a certain agricultural idea among farmers with the aim of encouraging them to adopt it. This plan requires consolidation and continuity of all educational efforts, mobilizing human resources and material capabilities, and utilizing all available means of communication for campaign implementation while cooperating with all concerned parties in the local community. Previously, the traditional agricultural extension was insufficient in reaching a large number of farmers and in encouraging the adoption of recommended techniques. The extension approach based on extension campaigns has gained an advanced position and helped accelerate the dissemination and adoption of agricultural innovations, resulting in desirable changes in farmers' behavior and practices (Ihm et al. 2015; Boa et al. 2016) AECs have numerous benefits in addressing and combating challenges that threaten the agricultural sector and food security (Damanpour and Schneider 2006). For instance, the bird flu pandemic had significant negative effects on both the poultry industry and human health. Combating the effects of this problem requires great efforts from the state to plan and implement AECs in which all institutions of society, such as the Ministry of Agriculture, Health, Information, and Security, participate to reduce the negative effects of the bird flu pandemic in Third World Countries. AECs also help to reach the largest number of individuals in the targeted areas in a community within a short period of time by using multiple methods and means of communication in parallel to overcome individual differences between the targeted farmers, such as their abilities to understand, implement, and assimilate the main idea of the campaign. Exposure of farmers to many methods and means of communication during the activities of extension campaigns leads to a significant improvement in their knowledge and skills compared to exposure to only one means of communication (Tambo et al. 2019).

Agricultural extension campaigns that rely on information and communication technology are a model for this. They increase farmers' participation and improve knowledge about pest management practices and the adoption rate for pest management practices as a result of the diversity of communication methods during campaigns. While agricultural extension campaigns have many benefits, realizing these benefits requires providing the necessary funding for the campaign, coordinating with all relevant authorities, and implementing it in a timely manner using various methods and means of communication that are compatible with individual differences between farmers.

Factors for the Success of the Agricultural Extension Campaign: In order for the Agricultural Extension Campaign to be successful, it must possess the following characteristics:

(a) The campaign should be practical so that it focuses on important issues and problems affecting the majority of farmers in the local community where the campaign is being implemented.
(b) Solutions to agricultural problems should be directly obtainable and have practical applicability for farmers based on their current conditions.
(c) The campaign should focus on a single idea in order to ensure that it is present in the minds of the targeted farmers.
(d) Thorough planning is necessary to identify participants from relevant authorities and to assign roles to each of them.
(e) Coordination with all relevant parties is essential for integrating efforts and achieving a successful campaign.
(f) Choosing the right time for initiating the campaign is crucial.

(g) The opening day of the campaign activities should be organized with the participation of leaders of participating parties to provide a strong impetus and attract people's attention.
(h) Campaign period should be set during which all efforts will be intensified to draw farmers' attention to the campaign subject.
(i) All national and local media, including TV, radio, press, extension publications, and social media, should be utilized to draw attention to the campaign activities.
(j) The closing date of the campaign should be determined to ensure completion of all planned activities within the specified dates.
(k) The closing day of the campaign should be organized with the participation of all concerned parties and certificates of appreciation should be provided to participants. 12. Distinguished farmers should be honored to incentivize their participation in future campaigns and to encourage other farmers to participate.
(l) The most important results of the campaign should be announced to obtain lessons learned for future campaigns.

Adhikarya (1994) suggests that a strategic agricultural extension campaign is valuable and significant for agriculture extension services for various reasons. These include the fact that the approach relies on participation in the planning process to meet the needs of farmers, fulfill their requests, and solve their problems using strategic planning and effective multimedia approaches that take into account their individual differences.

5.4 Agricultural Extension Approaches

Strategic planning and participatory approaches play important roles in agricultural extension methodologies. They contribute to the efficient use of inputs and the maximization of outputs (Adhikarya 1994). The existence of various agricultural extension systems (governmental, cooperative, and community service) that are compatible with the nature and traditions of each community contributes to increasing the efficiency of the agricultural extension system and positively impacts achieving food security. Each extension system has its own characteristics that enable it to achieve its objectives based on the determinants present in the agricultural community. These determinants include financial resources, human resources, legislation, and access to transportation and localization of agricultural innovations. To achieve the objectives of extension work, many agricultural extension systems worldwide use various extension approaches specific to each region. These systems include general agricultural extension, training, and visiting, project-based, commodity-based, farm systems-based, cost-sharing, educational institutions, and private sector approaches. Each approach has its own importance and method used in providing extension services based on the circumstances of each community and the characteristics of the target audience (Ismail et al. 2009). The strategic agricultural extension campaign's activities are an example of the extension approaches based on the agricultural systems approach. This approach begins with a survey of farmers' knowledge, attitudes, and practices (KAP) as a basis for planning and implementing the activities. Then, a series of extension workshops are implemented with the participation of extension agents, specialists, farmers, and leaders to increase their efficiency in planning extension programs, developing extension work strategies, designing and developing agricultural educational media, and enhancing farm management practices and functions in terms of planning, implementation, monitoring, and evaluation (Adhikarya 1994).

5.5 Expert Systems

Expert systems are a type of artificial intelligence application used in various fields including agriculture, medicine and engineering. In agriculture, the expert agricultural system is utilized to manage crops and simulate the work of a human expert. It contains the necessary expertise to solve specific problems in a particular field, aiding less experienced individuals seeking technical recommendations. This system interacts with its user, asking the same questions a specialized expert would and arriving at solutions to agricultural problems. It has practical applications in the agriculture sector, contributing to solving agricultural problems and making appropriate decisions in record time, ultimately resulting in an increase in quantity and quality of production while reducing costs. Agricultural extension agents are a crucial source of agricultural information and consultancy services in sub-Saharan Africa as they assist farmers with solving challenges, particularly during the Fall Armyworm outbreak. Due to the high number of farmers/extensionists and the deterioration of infrastructure, access to remote areas may be limited (Anderson and Feder 2007; Aker 2011; Bell 2015; Alfarisi et al. 2018). However, an expert system was developed that utilized a drone to identify pests and diseases of rice, proposing solutions and relaying messages to farmers about current situations, improving rice productivity and cost-effectiveness. Food insecurity is when one is unable to access food physically, economically, and socially. To address this, the Australian program for food relief focuses on the charitable food sector as an alternative to policies that support achieving food security. Decision-makers face challenges in accessing reliable evidence for interventions to support household food security and comparing policy options. Expert systems and modeling methods have been used as tools to estimate and compare available political options in the field of food security (Kleve et al. 2018). To correctly use an expert system and deal with it, users must differentiate between a question and a problem, problem and opinion, causes, symptoms and conditions, and cause and consequence, allowing for more efficient solving of agricultural problems. Modern AI techniques are expected to lead to a boom in expert systems, similar to the recent development of the chat GPT system.

One of the most important advantages of expert systems in agriculture is that they are easy for farmers to use. They can also be effectively applied in many agricultural crops and provide technical recommendations. The expert system can display its content in a simple manner and interact with non-specialists to produce a good result. Additionally, the system can interpret the solutions it reaches and indicate how it reached them. It is equipped to respond to simple and complex questions within the data available in the system, and is a useful means of providing high levels of expertise. This is particularly important in cases where there is a lack of sufficient experts or inadequate guidance systems. Furthermore, the system increases the capabilities of specialists with minimal experience and helps them develop their knowledge and expertise. Despite these benefits, expert systems in agriculture do face several issues. Firstly, they tend to be more costly to design, operate and maintain compared to traditional applications. Secondly, there is often a lack of qualified human capabilities to establish and operate the systems. Thirdly, recommendations may be invalid for application in different regions, and the system needs to take into account geographical differences. Fourthly, there is a lack of computers in extension centers, especially in poor countries. Agricultural extension agents also require more training to deal with expert systems. Finally, the efficiency of an expert system may decrease if the problem differs slightly from the recommendations stored in the databases. Additionally, illiteracy among farmers can be a hindrance to their use of expert systems.

6 Agricultural Extension Privatization

Many countries worldwide have implemented different government arrangements aimed at providing various sources of funding for agricultural extension activities to provide extension services appropriate to the nature of their society. These arrangements are known as "privatization". Privatization has various effects on the extension service. In its broad sense, agricultural extension privatization allows the private sector to participate in extension work, which does not necessarily mean transferring ownership of state-owned assets to the private sector. It is worth mentioning that privatization focuses on recovering the costs of the service or part of it, or marketing the extension services to ensure the availability of self-financing for the extension agencies. This enables them to continue performing their tasks and enhances the quality of provided extension services. According to Uddin and Qijie (2013), the privatization of agricultural extension services aims to reduce government spending and increase the efficiency and quality of extension services provided to farmers.

In 1980, the general view of agricultural extension began to develop globally. This was considered a turning point and marked the end of a significant stage in the growth of extension services funded by governments (the public sector). Agricultural extension is now recognized as a mechanism for knowledge and technology transfer that enhances rural development. In the past, the transfer of knowledge and technology was the responsibility of the government sector. These changes indicate the development of non-traditional models for providing extension services that have quickly become models for providing extension services in third world countries. This is reflected in the ability of the agricultural sector to achieve economic growth and increase opportunities for education and well-being for the population and small agricultural producers in rural areas. The implementation of the GATT Agreement has had many impacts on developing countries, particularly the increase in comparative advantages of agricultural products. A closer analysis of the global trade of agricultural crops reveals that most developing countries still have a great opportunity to increase the productivity of agricultural crops and animals which helps achieve food security. This can be attributed to the fact that productivity rates in those countries are still low compared to their counterparts in developed countries. This highlights the importance of agricultural extension roles and tasks in developing countries, where agricultural extension performs a variety of tasks that contribute to the development of the agricultural sector (Swanson 1990).

The presence of traditional production patterns and a high percentage of illiteracy among farmers require more efforts to increase the diffusion and adoption of agricultural innovations in targeted rural areas. This will contribute to more availability of locally produced agricultural commodities and limit imports, ultimately leading to an increase in the food self-sufficiency ratio and the achievement of food security. However, with the shift towards policies that encourage greater market economic freedom, competition in the agricultural sector often favors developed countries at the expense of developing countries due to the existence of a large scientific gap and preferential conditions. This highlights the importance of agricultural extension in transferring and adopting modern agricultural innovations to reduce this scientific gap. While agricultural extension has existed in some form since the nineteenth century, it became an official institution in many countries during the 50s and 60s of the twentieth century. Agricultural extension initially arose in capitalist countries before spreading to developing countries as these nations rebuilt after World War II. Recently, many countries have faced multiple economic challenges such as economic slowdowns, limited production resources, soaring food prices, increased rates of poverty and food insecurity, population growth, climate change, the COVID-19 pandemic, and conflicts such as the war in Ukraine and changes in economic policies. These issues have limited government intervention, including in the management of economic affairs and agricultural extension services. Despite concerns about the costs of financing agricultural extension, well-managed extension agencies can deliver benefits to society in terms of economic and social returns by upgrading the knowledge, skills, and attitudes of farmers, leading to increased incomes and household food security.

It can be argued that not all justifications for spending are beneficial to society. This is in part due to the difficulty in measuring the direct impact that the transfer of modern agricultural technologies may have, as their economic returns may not be apparent in the short term. However, investing in such technology can have positive effects on human development in rural areas. For instance, a field study conducted by the author in the short term region of Egypt found that the majority of farmers were willing to contribute to the costs of professional extension services that could improve their productivity and help them market their products more effectively, as they often fall prey to exploitative brokers and traders in the developing world. Despite these benefits, the government's extension sector is often criticized for its high costs, inefficiency, and failure to meet the goals of rural communities adequately. This has led to recommendations that suggest structural changes to improve its ability to support farmers. Three policies have emerged regarding the privatization of agricultural extension: government funding for services directly benefiting farmers, direct fees on select services, and joint funding from public and private sectors to support activities with shared benefits. Additionally, the current global situation demands that commercial standards be applied to extension services. Institutions must rely on consulting fees from farmers and government contracts while also providing information to the government on the challenges and proposed solutions for the agricultural sector. Some countries have adopted the extension voucher policy, where government agencies distribute coupons to farmers for use in paying for private sector consultants. Others attach coupons to agricultural bank loans, allocating a percentage for extension services. However, while privatizing agricultural extension is essential, it should occur gradually, allowing for a smooth transition from government to private extension services.

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In order to effectively carry out its tasks, agricultural extension utilizes various methods such as individual, group, and mass extensions. These methods include farm visits, telephone calls, meetings, field days, training courses, workshops, agricultural extension campaigns, expert systems, and applications. With regard to food security, agricultural extension provides advisory services to assist farmers in adopting and utilizing technologies for crop and livestock production. Extension workers fulfill various roles, such as trainers, consultants, project managers, and advocates for agricultural plans and policies. They also offer administrative support to local governments and assist farmers in making decisions and sharing knowledge. It is important to note that adopting technologies improves agricultural practices, thus resulting in increased productivity and improved quality of animal and plant products. These improvements strengthen the pillars of food security, including availability, accessibility, and utilization. Increased productivity leads to greater availability of food and higher farmer incomes, which enhances their purchasing power. It can also

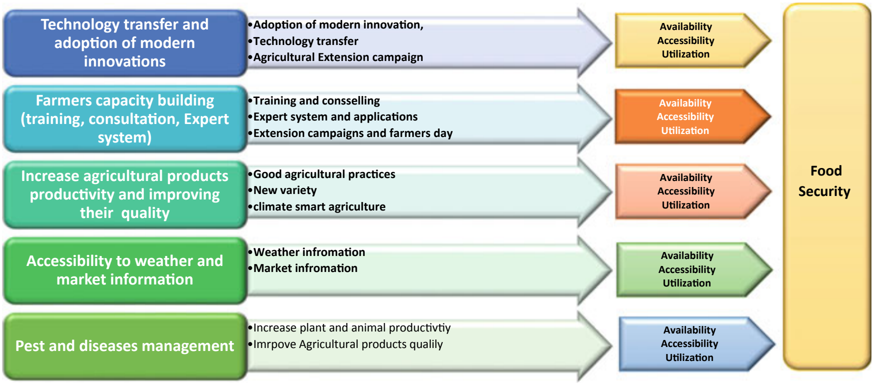

Fig. 4 The effects of agricultural extension methods and activities on food security. *Source* Prepared by the authors

result in lower food prices, benefiting consumers and sustaining food systems, while preserving agricultural resources amidst population growth and climate change. Another important task of agricultural extension is to raise awareness about pest and disease management. Pests and diseases have significant impacts on all aspects of food security. Infection can decrease production, negatively affecting the pillar of food availability, while farmers may incur reduced quantities of produce, leading to higher prices that impact consumers' access to food. Furthermore, pests and diseases affect the quality and safety of food products, leading to food loss and waste. Therefore, the transfer and adoption of good pest control practices contribute to improving food security indicators for food availability, access, and utilization.

7 Agricultural Extension in Saudi Arabia

7.1 The General Administration of Agricultural Extension (GAAE), Role and Responsibilities

The Kingdom of Saudi Arabia is situated on the Arabian Peninsula and spans over 2 million square kilometers. The country is divided into 13 regions, each of which contains several governorates, cities, and villages. The Ministry of Environment, Water, and Agriculture (MEWA) is responsible for overseeing the agricultural sector and maintaining its operations across various regions. One of the divisions within the MEWA is the General Administration of Agricultural Extension (MEWA 2023).

According to MEWA (2023), the General Administration of Agricultural Extension (GAAE) acts as a coordinator between research centers and farmers in order to identify and address current agricultural problems. Extensionists are responsible for transferring the results of agricultural research and problem solutions to farmers, with the aim of raising farmers' awareness and developing their skills in applying modern agricultural production technologies. These efforts are aimed at improving food production to meet the needs of consumers and reducing food imports, increasing farmers' income, raising the standard of living of rural households, and preserving natural resources. In MEWA, the GAAE is responsible for apiaries, bees, beekeepers, queen bee-rearing stations, and the distribution of queens and bees. Additionally, the GAAE plays an awareness role by issuing extension publications, agricultural diaries, extension leaflets, agricultural pamphlets, display shelves, and educational films. The GAAE is responsible for providing agricultural extension services that take into account the geographical and cultural diversity between the regions of the Kingdom. The GAAE supervises the management and directing of all extension services provided by the directorates and branches of the ministry to farmers, livestock breeders, fishermen, beekeepers, and those interested in agriculture throughout the Kingdom. In order to accomplish its goals, the GAAE has outlined several tasks and responsibilities. These tasks include developing policies and standards for agricultural extension services, including those for veterinary, fisheries, and plant extension. Additionally, the GAAE aims to establish standards for model extension fields in all regions of the country, in order to apply the results of research activities in accordance with each region's comparative advantages. The organization also works to set standards for educating farmers and extension service beneficiaries in the areas of aquaculture and livestock projects. Furthermore, the GAAE is committed to raising the quality of extension services provided in various fields of organic agriculture. To ensure the most effective and up-to-date services, the GAAE plans to identify and include pioneering practices, modern agricultural technologies, and methods in extension and awareness services. The organization also determines awareness programs according to pioneering practices, such as the use of greenhouses. The GAAE will also develop plans for the preparation, issuance, and distribution of pamphlets, posters, videos, audio movies, Internet and social networking services, as well as a specialized guidebook. It will follow up to ensure the quality of counseling and awareness services provided by external parties, making sure they adhere to established standards, controls, and policies. In addition, the GAAE works to disseminate and adopt agricultural innovations and technologies while establishing a strong connection between extension and agricultural research. The organization also supports the concept of participation in building extension programs and works to raise the efficiency and productivity of farms.

The General Administration of Agricultural Extension is made up of three departments: plant extension, veterinary extension, and fisheries extension.

7.1.1 Tasks of the Agricultural Extension Department Concerned with Plant Production

The tasks of the Agricultural Extension Department concerned with plant production include:

(a) Identifying agricultural problems and obstacles and research priorities in collaboration with the General Departments of Agriculture Affairs, Directorates of Agriculture, and Agricultural Research Centers.
(b) Strengthening the relationship between the MEWA and farmers through agricultural extensionists in the General Departments of Agriculture Affairs and the Directorates of Agriculture and their affiliated branches.
(c) Facilitating communication and collaboration between research centers, universities, and farmers to disseminate research results across various fields of agriculture and providing extension information to farmers. Additionally, conveying the challenges faced by farmers to research centers.
(d) Transferring modern technologies to farmers to enhance production quality and quantity, minimize production costs, and increase farmers' income while preserving natural resources and water.
(e) Collaborating with the Directorates of Agriculture to plan, implement, and evaluate extension programs.
(f) Contributing to the development of internal and external technical training programs for agricultural extensionists.
(g) Organizing and conducting workshops, seminars, meetings, and field days for agricultural extensionists, farmers, and other stakeholders (MEWA 2023).

7.1.2 Veterinary Extension Department

The tasks of the Veterinary Extension Department are as follows:

(1) Planning and preparing extension programs aimed at raising the awareness of livestock and poultry breeders, developing the performance of both veterinarians and those working in the veterinary field, and following up and evaluating their implementation in cooperation with public administrations and agricultural directorates.
(2) Educating and guiding breeders by delivering recommended veterinary information in an easy and simplified manner through extension campaigns.
(3) Utilizing distinguished internal and external expertise in the field of veterinary extensionists to participate in training courses, workshops, and extension campaigns.
(4) Building the capacity of veterinary extensionists in Saudi Arabia.
(5) Monitoring disease cases and addressing problems faced by animal owners through continuous communication and delivering veterinary extension information (MEWA 2023).

7.1.3 Fish Agricultural Extension Department

The tasks of the Fish Agricultural Extension Department are as follows:

(1) Planning, implementing, and evaluating fishery extension programs that ensure protection, development, and good utilization.

(2) Conveying the results of fisheries research and scientific studies to fishermen in an easy and simplified manner through extension activities.
(3) Transferring expertise, skills, and modern fishing technologies to fishermen through extensionists with the aim of raising their work efficiency and increasing their productivity.
(4) Raising awareness among fishermen about laws and regulations related to fishing and the importance of adhering to their implementation.
(5) Developing appropriate extension means for implementing extension programs in the field of fisheries (MEWA 2023).

7.2 Achievements of the General Administration of Agricultural Extension (GAAE)

The GAAE is dedicated to promoting and sustaining the agricultural sector in Saudi Arabia. Some of their significant achievements in agricultural extension include.

7.2.1 Small Farmers Support Program

This program aims to educate and improve farm productivity for small farmers in the industry, including beekeepers, small producers, fishermen with Ministry licenses, and other small farm owners. The program provides various instructional seminars, workshops, and informative materials like leaflets, pamphlets, and posters. Extension and technical teams connected to the agricultural department assist with activities, such as fertilization, irrigation, and pesticide application. In addition, tools and equipment like red palm weevil traps, fertilizers, pesticides, occupational safety tools, and spraying equipment are distributed to farmers. In the year 2023, 585 farmers in multiple departments and directorates of agriculture benefited from the program, and GAAE plans to implement this program in all regions of the kingdom. This program has already started in regions like Jazan, Al-Baha, Asir, Qassim, Eastern Province, Madinah, and the governorates of Unaizah and Al-Ahsa, gaining remarkable approval and interaction from participating farmers ((MEWA 2023).

7.2.2 Executed Extension Programs and Activities

GAAE has implemented over 405 extension programs and activities annually in Saudi Arabia, including 45 model fields, 69 extension symposiums, 88 workshops, 89 extension meetings, 24 general agriculture extension events, and 90 field visits. Also, GAAE participates in national conferences such as the Saudi Agricultural Exhibition and the National Festival for Heritage and Culture. Out of 39 agricultural extension development projects, 62% were allocated to plants, 23% to bees, and 15% to fishery projects (MEWA 2023).

7.2.3 Agricultural Awareness

Various brochures have been developed to provide information on different agricultural topics, including modern irrigation systems, red palm weevil, logging and desertification, irrigation and fertilization programs for palm trees, coral reefs in the marine environment, mangroves, safe use of pesticides, and protected agriculture, as well as forage farming alternatives. These guides have been printed and distributed in large quantities, with nearly a quarter of a million copies being disseminated.

7.2.4 Agricultural Nurseries

The Agricultural Extension Department is involved in several activities related to agricultural nurseries. These include supervising nurseries that produce fruits, vegetables, and forest seedlings, as well as encouraging farmers to establish open agricultural nurseries. In addition, plants with comparative advantage and rare plants from each region are cultivated to preserve and sustain these species. Seedlings are also distributed to farmers on certain occasions, and improved varieties of plants are promoted for cultivation.

7.3 The Agricultural Guide Application (Murshiduk)

It is an electronic platform designed to facilitate communication between Saudi Arabian farmers, agricultural extension agents, and agricultural experts. This application is one of the outputs of the Saudi GAP initiative, developed in collaboration between the Ministry of Environment, Water, and Agriculture (MEWA) and King Faisal University. The launch of the Murshiduk application is part of MEWA's efforts in digital transformation and the development of its electronic services offered to farmers. The Murshiduk application aims to provide online agricultural consulting services to farmers across various regions of Saudi Arabia using mobile phone applications. Since approximately 80% of extension services required by farmers are knowledge and advisory services, the application hopes to efficiently address these demands, which are often placed via remote requests and outside traditional extension services provision centers due to Saudi Arabia's large geographical area of 2 million km^2. The importance of the Murshiduk application has increased due to the outbreak of the COVID-19 pandemic, where it has become an effective means of communication between agricultural extension agents, experts, specialists in the Ministry, and between farmers, agricultural companies, and other institutions. The application aims to connect both parties through audiovisual communication and relies on more than 300 agricultural experts within Saudi Arabia to provide extension services. The success of the application is attributed to the development of Saudi Arabia's digital infrastructure, which has achieved advanced rankings in the Middle East and the world for its internet services. High levels of income in the country have enabled farmers to access advanced technologies, such as smartphones and tablets, providing them with the ability to use the application with ease. As of February 2022, data from GAAE reported that 209,789 farmers benefit from the Murshiduk application, with 204,531 within Saudi Arabia. The application has more than 390 specialized and experienced agricultural extension agents who offer advisory and extension services in various regions within the country. The application has facilitated over five months of agricultural extension work, where 395,176 messages were exchanged, 182,467 phone calls, 13,746 questions were asked, 12,764 extension publications were posted, 55 virtual workshops and events hosted, and 68 various live broadcasts were made.

7.4 Agricultural Extension Campaign in Saudi Arabia

In Saudi Arabia, the Ministry of Environment, Water, and Agriculture has implemented a program of extension campaigns for various agricultural regions. The goal of these campaigns is to increase farmers' knowledge and skills in agriculture, by changing their behavior and applying best practices suitable for each region's comparative advantage. Additionally, the campaigns aim to introduce farmers to modern technologies, change negative practices in pest prevention, and teach them the necessary skills to combat pest problems. The promotion of good agricultural practices, such as "Saudi GAP," is also highlighted due to its relevance to achieving food security. Each regional branch of the Ministry will organize a three-day agricultural extension campaign. This event includes seminars, presentations, workshops, and product displays, involving government agencies, NGOs, farmers, livestock breeders, productive families, and beekeepers. Saudi Arabia's extension campaigns are noteworthy for their long-distance travel between six regions and are expected to enter the Guinness Book of Records. The campaigns have received great attention from officials, academics, and farmers, and achieved success in meeting various stakeholders from specialized, technical, popular, and academic associations.

7.5 Agricultural Extension Saudi Good Agricultural Practices (SAUDI GAP)

The Ministry of Environment, Water, and Agriculture in Saudi Arabia has adopted various initiatives aimed at implementing good agricultural practices in cooperation with King Faisal University and the Dutch University of Wageningen as scientific partners. One of these initiatives is proposing and drafting the legal legislative framework for Saudi Good Agricultural Practices (Saudi GAP), which sets the specific timetable for farmers to join Saudi GAP, starting with large farms, then medium farms before applying to small farms as the last stage. The initiative includes mechanisms to support small farms to join Saudi GAP program. The Saudi GAP initiative includes a set of standards for different kinds of farms, starting with general standards for the farms, and then with standards for specialized farms, including vegetable, grain, fruit and dates palm farms. These standards are necessary because the dates palm is one of the most important agricultural crops in the KSA and represents an important part of the customs and traditions of hospitality in Saudi society, in addition to other standards related to farms of livestock, fish production, and food industries.

The standards are implemented according to specific work mechanisms, and the legal framework is developed to ensure the adoption of global agricultural practices (Global GAP). A separate initiative was also launched to develop agricultural practices to boost the productivity of various crops including vegetables, fruits, dates palm, and field crops in the Kingdom of Saudi Arabia. This initiative focuses on rehabilitating the infrastructure in the agricultural sector by establishing extension fields and field laboratories in various regions, and this will be used to disseminate agricultural techniques, transfer technology, and train farmers in different regions to prepare them for joining the initiative of Saudi GAP.

8 Conclusion and Prospects

Promoting agricultural development through effective agricultural extension services is essential for ensuring food security around the world. The agricultural sector is the primary source of food for human consumption and provides many raw materials for various industries such as textiles, furniture, leather, and others. As education and health services improve, and citizens become more aware, their demand and expectations for variety and quality of agricultural products increase. Therefore, effective agricultural extension services are necessary. The agricultural extension apparatus is essential in simplifying science and scientific research, transferring it to farms, and educating and assisting farmers in applying techniques to improve the quality and quantity of their production. This chapter discusses the concept of agricultural extension, the philosophy of extension work, the objectives of extension work, and the relationship between agricultural extension and food security. Additionally, we explore extension work mechanisms and how they can increase farmers' knowledge and skills, which can lead to improved productivity and quality of agricultural crops. This has significant implications for achieving local food security by providing goods to domestic consumers and the international community. The COVID-19 pandemic and the Ukraine war have caused a significant rise in the prices of agricultural commodities and a shortage in food supplies, especially in developing countries that depend on importing food from abroad. This situation emphasizes the need for countries to reconsider their self-sufficiency ratio of locally produced food and provide more support and development for agricultural extension agencies. This support is necessary to increase their ability to advance the local agricultural sector by providing modern agricultural practices and efficient extension services. The most important action extension agencies can take in the future is to develop their capacity building and develop the skills of agricultural extension workers so that they can make a real contribution to the development of the agricultural sector based on modern scientific recommendations and sustainable agricultural systems. Despite the global economic conditions that may hinder governmental agricultural extension, promoting agricultural development through effective agricultural extension services remains essential to ensuring food security in various countries of the world.

It is possible to recommend procedures that can be applied in the field of extension work, particularly in developing countries. Examples include modern agricultural techniques for agricultural extension, such as strengthening sub-laboratories for diagnosing plant diseases, detecting pathogens using the ELISA technique, polymerase chain reaction (PCR), Biolog System, Biosensors, electronic prediction software technologies, and other technologies that farmers can use themselves through simple devices that give quick readings on the farm. Farmers should also be trained to use them. Techniques in the field of irrigation systems and agriculture, such as the use of developed irrigation systems, determining water needs, remote sensing techniques, applications of solar energy in agriculture, use of soil conditioners, use of soil moisture sensors, use of modern irrigation systems operating devices, use of magnetized water in irrigating vegetable crops, rapid propagation techniques through tissue culture machinery, use of mechanization in cultivation and harvesting to reduce losses in agricultural crops, the use of automatically grafted seedlings, cooperation with research centers in the production of improved seeds of the most important local varieties with comparative advantage and dissemination among farmers,. techniques in the mechanisms of providing agricultural extension services, including developing a website that provides interactive electronic extension service (e-Extension), designing and implementing electronic applications for use with smartphones to facilitate farmer interaction, especially in light of natural disasters and global health crises that impede access to farmers, establishing farmers Call Center, developing expert systems programs, and developing some of the current extension centers to become advanced centers for media support and development.

It is possible to recommend certain procedures that can be implemented in the field of extension work, particularly in developing countries. For instance, the use of modern agricultural techniques can be employed for agricultural extension purposes. This could involve fortifying sub-laboratories that diagnose plant diseases, detecting pathogens with modern techniques such as Polymerase Chain Reaction (PCR), Biolog System and Biosensors. Secondly, farmers can use other technologies through simple devices that provide quick readings on the farm, and farmers can be trained to use them. For instance, the techniques for irrigation and agricultural systems, including the use of advanced irrigation systems, remote sensing techniques, the application of solar energy in agriculture, the utilization of soil moisture sensors, and mechanization and harvesting can also be incorporated to help reduce crop losses. Thirdly, the implementation of practices to provide agricultural extension services could be useful. This would include developing a website that provides an interactive electronic extension service (e-Extension), designing and implementing electronic applications that are used with smartphones to facilitate interaction with farmers, especially during natural disasters and global health crises that impede access to farmers, such as wars and disease pandemics. Also, establishing a Farmer Call Centre and developing Agricultural Expert System could prove beneficial.

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Chapter 14
Agricultural Mechanization and Food Security in Saudi Arabia

Mohamed Ahmed Elbashir

Abstract Agricultural mechanization has evolved from the use of hand tools to draft animals, to motorized machinery, to digital equipment, and finally to robots using artificial intelligence. These improvements enhance productivity and improve the management of crops, livestock, aquaculture, and forestry. This, in turn, leads to better working environments, increased income, reduced labor-intensive work, and the creation of new rural business opportunities. The global population is growing rapidly and is projected to reach 8.5 billion individuals by 2030 and 9.7 billion by 2050. This poses a significant challenge for the agri-food industry, which must find ways to feed more people. Additionally, the loss of agricultural land due to urbanization and industrialization further emphasizes the need for efficient production methods Precision agriculture has the potential to be the solution. It is a management practice concerned with the precise application of agricultural inputs such as seeds, fertilizers, water, pesticides, and energy, with the ultimate objective of reducing the costs of such inputs, increase yield, improve returns, and mitigate the environmental risks of farming. Practicing of PA includes collection of data such as soil, crop and yield data, then processing them through computer models for the generation of prescription maps and finally precise application of the agricultural inputs through variable rate application devices installed in the agricultural implements. Saudi Arabia is the biggest country in the gulf region with a total area of about 2.3 million km^2 and a total population exceeding 28 million. The cultivable land in Saudi Arabia accounts for 1.6% of its total area resulting in 0.11 ha per capita arable land that is globally among the lowest ones. Saudi Arabia has been classified as "water stressed" country, and sever water scarcity is expected by the year 2050. The un-sustainable agricultural activities resulted in a rapid depletion of the non-replenish aquifers of the country. This situation necessitates changing the current farming practices so as to challenge food insecurity problems. To enhance

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its agricultural production to ensure food security Saudi Arabia needs to adopt the precision agriculture approach.

Keywords Agricultural mechanization · Enhancing productivity · Food security · Precision agriculture · Saudi Arabia and water scarcity

1 Introduction

Mechanization refers to the use of machinery and equipment, ranging from simple hand tools to advanced, motorized machinery, so as to perform agricultural operations (Sims et al. 2016). In the past, a significant amount of agricultural work relied on manual labor or the use of animals. However, in most countries around the world, this has changed due to the introduction of machines that require energy to function. Agricultural mechanization encompasses the choosing, operating, utilizing, and maintaining of mechanical devices and systems involved in agricultural operations and production, aiming to maximize the benefits for humans (Bello et al. 2021). That is to say to enhance the investment in mechanization technologies and their sustainable adoption, definite environmental, agricultural, social, and economic conditions have to be met (Ou et al. 2002). The incorporation of machines in farming since the industrial revolution has resulted in saving of manpower in agricultural practices. Agricultural mechanization is part of this technological development to reach automation in agriculture (FAO 2022a). The progression can be summarized as a move from using of hand tools to draft animals, to motorized machinery, to digital equipment, and finally to robots using artificial intelligence (AI) (FAO 2022b). These advancements increase productivity and ameliorate the management of crop, livestock, aquaculture, and forestry, resulting in a better working environments, improving revenues, reducing the workload in agriculture, and creating new rural business opportunities (FAO 2022b). In the present agricultural mechanization tractors, trucks, combine harvesting machines, various farm equipments, airplanes, helicopters, and drones for aerial application, and other vehicles were used.

When more power is supplied to agriculture, it is possible to achieve timeliness in agricultural operations and farm larger acreage to increase the agricultural production while preserving natural resources. This can be achieved by utilizing latest technologies that are less harmful to the environment, which lead to large produce and economically feasible farming process with less power used.

The fundamental requirements for humans to survive include food, clothing, and housing, with food being the most decisive factor for sustenance. Food is produced directly through primary agricultural production and is regarded as the most crucial of the three essential needs. Consequently, agriculture is a profession that saves lives (Bello 2012). Achieving food security means availability and affordability of enough, healthy and balanced nutrition at all times to every individual within a region or country, as stated by the FAO (1996).

2 The Role of Mechanization in Agriculture

Agricultural mechanization has the greatest impact on enhancing agricultural production by increasing farming efficiency, productivity, and profitability (Kumar 2017). Here are some ways in which agricultural mechanization contributes to increased agricultural production.

(a) Enhanced efficiency: Agricultural mechanization reduces the time and labor required for various farming operations such as land preparation, planting, and harvesting. This allows farm's tasks to be carried out more efficiently and quickly, leading to increased productivity and output.
(b) Improved crop quality: Mechanized farming equipment provides more precise control over various farming operations such as planting depth, spacing, and fertilizer application. This results in more accurate and consistent crop production, which can improve crop quality and yield.
(c) By utilizing mechanized farming equipment, the production capacity of farms can be increased. This is because such equipment can cover larger areas of land at a faster pace compared to manual labor. As a result, farmers are able to produce more crops in a shorter period of time. Moreover, this allows them to capitalize on beneficial weather and growing conditions (Kumar 2017).
(d) Improved crop resilience: Mechanized farming equipment can help farmers respond more quickly and effectively to weather or pest-related challenges. For instance, such equipment can be used to apply pesticides or fertilizers more precisely or harvest crops before they are damaged by weather events.
(e) Better market access: Mechanized farming equipment can help farmers produce crops that meet market demands for quality, quantity, and consistency. This allows them to sell their products at higher prices in local or global markets. Overall, the use of agricultural machinery can help farmers increase their productivity and profitability in farming. Additionally, it can improve the quality and resilience of their crops. However, it is important to recognize that adopting mechanized farming practices may require a substantial investment in equipment, infrastructure, and training, which could be difficult for some farmers. Agricultural mechanization has a significant impact on agricultural production and profitability. It involves using machines and equipment such as tractors, harvesters, and planters to replace human labor in various farming operations (Bello 2012). By utilizing mechanization, farmers can boost their productivity and efficiency since machines can complete tasks more rapidly and precisely than humans. This could result in higher yields and lower production costs, ultimately leading to increased profitability. Additionally, mechanization can help effectively manage crops and resources, resulting in precise and consistent application of fertilizers, pesticides, and herbicides. This can improve crop quality and reduce losses caused by pest infestations and disease outbreaks (FAO 2017). Moreover, agricultural mechanization can have positive effects on rural development. It can improve food security, create job opportunities, and enhance the living standards of farmers and their families. In conclusion, agricultural

mechanization is a crucial tool for sustainable agricultural development, especially considering the growing global population and demand for food (FAO 2017). Below are some examples of research findings that explain the role of mechanization in agriculture. Xiaoshi and Wanglin (2022) conducted a study examining the effects of adopting various mechanized farming techniques (such as completely non-mechanized, partially mechanized, and fully mechanized) on land productivity in the People's Republic of China. Their findings revealed that implementing semi- and fully mechanized farming methods boosted land productivity, with the greatest impact occurring when applying the fully mechanized technique. Specifically, adopting the semi-mechanized system increased land productivity by 35.8%, while the fully mechanized one increased it by 67.2%.

Pingali and Binswanger (1984) conducted a review of 24 studies on labor usage in farms using animal draft power compared to those using tractors in Asia. Their findings showed changes in labor usage across different operations, as well as total labors involved and changes in their levels of use between operations. Of the total number studied, 22 were found to have use lower total labor/ha of crop production for farms using tractors as opposed to those relying on animal draft power. In 12 studies, labor use was reduced by 50% or more. The most significant decrease in labor use was observed in land preparation, where in all studies a reductions in labor input that exceeding 75% was reported.

Rice is a staple food in Bangladesh, which in its transplanting manual labor is used. According to Rao and Pradhan (1973) a delay in the transplanting process by one month can result in a crop yield reduction by 25%, and delaying it by two months can reduce the yield by up to 70%. As a result, mechanical transplanting can be viewed as a solution to this labor-intensive process. Islam et al. (2016) found that manual planting in Bangladesh requires approximately 123–150 man-hours per hectare, whereas when using four-row walking transplanters mechanical transplanting requires only 9–11 man-hours per hectare.

Cotton production involves several methods such as land preparation, planting, weed control, spraying, and picking. Amongst all these methods, cotton picking is the most arduous, and labor-intensive operation. Mishra et al. (2023) conducted research and reviewed the current development in cotton harvesters, which are used for Indian cotton production. The researchers found that in India, multi-stage handpicking of cotton crops is common and typically involves about 500 man-hours/ha. Sandhar (1999) reported that, an adult can pick around 15–20 kg of seed cotton/day. Whereas, a single-row spindle-type picker can collect anywhere between 870–2180 kg/day.

Irrigation in India is characterized by low efficiency due to unleveled land. Aryal et al. (2015) conducted a study to investigate the influence of land leveling using laser technology, in reducing irrigation water losses resulting from highly undulating fields. In their study they compared two types of land leveling systems: Laser land leveling (LLL) that uses laser equipped drag buckets, and Traditional land leveling (TLL) that uses scrapers or leveling boards mounted to tractors or drawn by draft animals. The experiment was carried out in Indian states of, Haryana and Punjab, under three cropping systems: Rice–Wheat, Cotton-Wheat and Sugarcane-Wheat, potato, vegetables etc. They concluded that LLL minimizes the amount of water applied in irrigation and maximizes crop yields. Reduction in Irrigation duration in fields laserly leveled by 47–69 h/ha/season in rice and by 10–12 h per ha per season in wheat was observed and yields of wheat and rice were 7–9% and 7% higher, respectively, in comparison to ones that traditionally leveled. Minimized irrigation period means less energy use in agriculture which in turn minimize the emission of greenhouse gas from agricultural production. Consequently, more use of LLL assists in climate change alleviation. Moreover, using reduced amounts of water for irrigation creates opportunities to allocate the saved water for other purposes in the economy, such as addressing the demands of growing populations, industrial development, and urban expansion.

In Africa the traditional factors of labor force, agricultural land and livestock are the basis for the increase in agricultural production, with special emphasis on increasing the area under cultivation and the abundant use of labor (Djoumessi et al. 2020). As a result, there will be minimal or no improvement in the productivity of agricultural output for each unit of inputs. Enhancing productivity primarily depends on factors other than basic inputs, such as inventions, research and development, and rural infrastructure. Djoumessi (2021) conducted a study, on a sample consisting of 22 countries in the Sub-Saharan African region from 1996 to 2014 to examine the key factors influencing agricultural productivity, with a particular focus on agricultural innovations. Among the innovations that enhance productivity, it was observed that the components of fertilizer have a limited effect on agricultural productivity growth. In contrast, the use of pesticides and irrigation practices have a positive and significant effect on agricultural productivity. Regarding innovations that minimize cost or agricultural labor, the study indicates that the use of tractors and harvesting machines have a significant and important positive impact on agricultural productivity. Whereas threshing machines were found to have extremely low or non-existent effect on agricultural productivity in Sub-Saharan Africa.

Enhancing agricultural operational efficiency goes beyond being an effective approach to maximize farmers' revenue and improve the efficiency of the agricultural sector. Instead, it forms a fundamental basis of the rural revitalization strategy. Peng et al. (2022) conducted a study aimed to determine the extent of the impact of agricultural mechanization on farmers' agricultural production and income. The study used a Data collected from a field survey performed in Hubei Province among households during the year 2018. The survey gathered important information about households, including their natural and physical assets, production and working conditions, land transfer behavior, and farmers' awareness of policy. The study was conducted in the districts of Jianli and Qichun in Hubei Province, China, where the level of agricultural mechanization is 66.75%. This level closely matches the overall level of mechanization for land preparation, seeding, and harvesting of main crops in Hubei Province. Typically, researchers measure the level of agricultural mechanization by considering the amount of power or net value of machinery used. These indicators are suitable for assessing the level of mechanization in a specific region, but they are not applicable for evaluating mechanization at the individual farm level. Therefore, it would be more appropriate to use the calculation method employed by the Ministry of Agriculture and Rural Affairs. This method involves calculating a weighted average of machine farming, seeding, and harvesting rates at the farm level, with weights of 0.4, 0.3, and 0.3, respectively (Peng et al., 2021). This method not only provides an easy way to obtain the indicator but also accurately measures farmers' machinery usage behavior. Researchers have made the following discoveries: Firstly, the level of agricultural mechanization significantly impacts the cost of production, output value, revenue, and yield for all crop types. Increasing the mechanization level by one unit leads to cost increases of 0.74 units for all crops, 0.55 units for grain crops, and 5.51 units for cash crops. Moreover, the output values increase by 5.48 units for all crops, 8.42 units for grain crops, and 2.52 units for cash crops. The corresponding revenue increases are by 3.143 units for all crops, 5.479 units for grain crops, and 1.694 units for cash crops. Additionally, the rate of return experiences an increase of 1.22 units for all crops, 1.59 units for grain crops, and 0.44 units for cash crops. From a heterogeneity analysis perspective, a noticeable impact of the mechanization level threshold on income was observed, with a threshold estimated at 0.28 ha.

3 Precision Agriculture

The global population is growing quickly. According to the United Nations (2019), the number of people on Earth is estimated to reach 8.5 billion by 2030 and 9.7 billion by 2050. This presents a significant challenge for the agri-food industry as it tries to find ways to provide food for more people. The increase in urbanization and industrialization is leading to a decrease in available land, which is essential for agriculture. This means that there is a greater need for efficient production methods. Precision agriculture (PA) has the potential to be the solution (Mizik 2023).

Precision Agriculture (PA) is a management approach dealing with precise application of agricultural inputs such as seeds, fertilizers, water, pesticides, and energy. Its objective is to save agribusiness inputs, maximize yield, improve profitability, and mitigate the environmental risks of agricultural production. Precision Agriculture (PA), also called precision farming, encompasses three categories of advanced management technologies (Say et al. 2017), which are: First, there are several technologies used for data collection, such as soil sampling and field exploration, yield monitoring and mapping, the global navigation satellite positioning system (GNSS), remote sensing, as well as field and crop scouting. Second, there are technologies for processing this data and making decisions, which include Geographical Information Systems (GIS), software for agricultural mapping, economic analysis, geostatistics, and modeling. Lastly, there are technologies used for applying these findings directly on the field, such as variable rate application, section control, GNSS-based guidance, and agricultural robots.

In precision agriculture approach the agricultural inputs are applied at variable rates in the field according to the spatial and temporal variability of soil and crop. The Variable Rate Technology (VRT) is a system in which the inputs are applied at variable rates in the right time and place based on soil and crop variation (NESPAL 2005). VRT is used based on either map or sensor approach. In the map based VRT system, maps data of soil, crop and yield are collected then processed by computer crop/soil models and finally a control map is generated. A data card is used to copy the control map to a display/processor unit that is connected to a controller unit which are both installed in the tractor cabin. Finally the controller unit is connected to a variable rate device installed in the agricultural implement which apply inputs at variable rates (Belal et al. 2021). In the sensor based VRT technology, sensors are used in measuring characteristics of the soil and crop. Then the sensor readings are connected to a processor unit, for analysis. The analyzed data are then connected to a controller unit. The processor and controller units are both installed in the tractor cabin. Finally the controller unit is connected to a variable rate device installed in the agricultural implement which apply inputs at variable rates (Belal et al. 2021). Nowadays major agricultural equipment manufacturers incorporate precision variable rate capability as standard fittings.

Below are a few examples of precision agriculture practices:

Tillage is the mechanical disturbance of soil for the creation of favorable conditions for crop growth. Hence tillage practicing create good aeration and absorbing capacity in soil, moreover it helps in pest control by eliminating their habitat (Aditya 2023). In conventional agriculture uniform depth tillage is practice throughout the field, hence it is called conventional tillage (CT). There are several drawbacks associated with this technique. Firstly, from an economic point of view, unnecessarily disturbing of soil in areas in which the soil structure and condition is unessential is wasting of time and energy (Keskin et al. 2011). Secondly, tilting the soil to incorrect depth can lead to damaging of soil structure, specifically by smearing wet plastic soil (Gill and Berg 1967), resulting in the formation of a non-permeable layer that hinders plant root growth and negatively impacts yield. Lastly, unsuitable tillage practices may make the soil vulnerable to erosion, causing nutrients to be lost to the environment through leaching and runoff rather than being retained in the soil and available for plants. Soil erosion and soil organic matter depletion are among the biggest sustainability challenges for CT. The adoption of Conservation Tillage (CVT) practices can address these issues and therefore contribute to sustainable farming systems (Bista et al. 2017). CVT stands for any tillage or farming method that aims to reduce erosion caused by water or wind by ensuring that plant residue covering at least 30% of the soil surface after planting (Gorucu and Keskin 2010). However, CVT is not recommended for soils with compaction issues. A third approach called variable-depth tillage (VDT) or precision tillage has emerged as an alternative technology. VDT focuses on optimizing the physical properties of soil in places only where tillage is necessary, by performing tillage at specific depths. This technology has been proven to reduce costs, labor, fuel consumption, and energy requirements. To successfully implement the VDT system, it is important to accurately determine and map the penetration resistance of soil spatially and at different depths throughout the soil profile. Meselhy (2021) conducted a field experiment to evaluate the effectiveness of the technology by measuring the depth of tillage based on soil penetration resistance at various depths. The experiment was carried out in five areas, each representing a different method of preparing the soil for planting: no-tillage (CVT), tillage at a uniform depth of 25 cm, tillage at a uniform depth of 35 cm, tillage at a uniform depth of 45 cm (all representing CT), and variable-depth tillage (VDT), which is also known as precision tillage. The study aimed to measure various factors including the rate at which fuel is consumed (FCR), the actual capacity of the field for planting (AFC), the power needed for the process (PR), the specific energy used (SE), the costs of operating (OC), the resistance of the soil to penetration (SPR), and the amount of sorghum produced (SY). The results demonstrated the presence of a compacted layer of soil between depths of 25 and 35 cm. Consequently, the VDT system was applied at a tillage depth of 35 cm. Around 47% of the entire field area needed to be prepared for planting. The findings indicated that the VDT system reduced FCR, PR, and OC by approximately 35%, 35%, and 23% respectively, compared to the UDT system. In contrast, AFC increased by about 21% for the VDT system compared to UDT. When it comes to the amount of sorghum produced, there was a 53% increase for the VDT system compared to UDT at a tillage depth of 25 cm, while decreases of approximately 8% and 11% were observed for the VDT system compared to UDT at tillage depths of 35 cm and 45 respectively. In the conventional agriculture the soil is uniformly managed, regardless of the local spatial variability of its characteristics; such a practice may exacerbate its degradation process (Jie et al. 2002). The impact of intense human activity on agricultural soils worldwide is a matter of great concern. Extensive research, such as the study conducted by Jie et al. (2002), has estimated that about 40% of agricultural soils across the globe are currently facing serious degradation problems. The annual loss of agricultural soils due to advanced degradation, is estimated at 12 million hectares. This loss of arable land has a profound impact on global food production and security; as a result annual 20 million tons of grains is anticipated as a reduction in productive capacity (Rickson et al. 2015). To alleviate the soil degradation problems the soil should be delineated to zones which are homogeneous in their properties and managed accordingly regarding the application of agricultural inputs with the ultimate intent of increasing crop and soil productivity. Oliveira et al. (2019) conducted an experiment in two fields situated in the district of Planaltina, state of Goiás, Brazil. Field 1 (F1) encompasses 312 ha and has an average elevation of 1068 m. Field 2 (F2), which is located 5 km away from the first field, covers an area of 297 ha and has an average elevation of 1000 m. In the two fields the forest was cleared during the 1980s for agricultural purposes, with conventional farming practices involving plowing and disking to cultivate grain crops. Starting from 1995, a system of no-tillage was practiced, in which a soybean–corn were grown in a rotation in summer followed by fallow in winter. After 2007, an intercropping pattern involving maize-brachiaria was introduced for the management of soil cover and livestock. Their study had two main objectives. The first objective was the delineation of the homogeneous management zones (HMZs) employing the multivariate analysis approach. The second objective was the assessing the impact of uniformly managing soil on the physical–hydraulic attributes of the delineated HMZ. The HMZ represented soil spatial variability at the mineralogy level. The delineation of the management zones involved three steps. First, soil samples were collected from the fields and laboratory analysis was performed. Second, statistical analyses were carried out, and the HMZ were defined. Third, spatial distribution of the HMZ in the field was confirmed and location of soil profiles and sample collection for soil quality analysis was selected. The HMZ were determined based on the physical attributes of the soil, such as bulk density and structural porosity. In fields where the soil spatial variability exhibited greater homogeneity (F1), the physical attributes were used. In fields where the variability was more complex (F2), the HMZ were defined based on chemical attributes. When examining uniform management, it was observed that in F1, a significant decrease in structural porosity occurred in 46% of the 312 ha. In F2, there was a more pronounced decrease in structural porosity, affecting 26% of the area, while an increase in bulk density was observed in another 24% of the surface layer (0.00–0.30 m). The experimental findings support the hypothesis that uniformly managing soil can exacerbate its degradation and potential erosion. Conversely, dividing the field into homogeneous management zones (HMZs) can lead to more appropriate and sustainable soil management practices.

One of the main benefits of precision agriculture is the improvement of resource allocation for agricultural inputs. Variable Rate Seeding (VRS) is considered as an accurate agricultural technology that can perfectly meter the seeding rate based on variables such as soil properties, terrain, meteorological conditions, and other factors (Šarauskis et al. 2022). VRS can adjust the desired seeding rate for each zone in the field according to the site-specific data layers of soil texture, soil electrical conductivity, pH, and yield maps. Remote sensing technology or other data that identifies yield-determinant factors can then be used to determine the optimal sowing method for each field area, allowing farmers to optimize crop density and achieve the highest agricultural and economic results. Currently, different proximal and remote sensor systems, contact and contactless device, mapping, and VRS modeling technologies are utilized to identify the variability of soil and crop. By implementing VRS practices, farmers are able to properly manage their farm risks and focus more on investing in parts of the farm that are potentially productive (Šarauskis et al. 2022).

Chivenge et al. (2022) conducted a review of the advances made in research on the Site Specific Nutrient Management (SSNM) approach, a precision farming method used in rice, maize, and cassava cropping patterns for small-scale farmers in Sub-Saharan Africa (SSA). Findings demonstrated that employing the SSNM technique leads to an increase in both yield and profitability, as well as improved nutrient utilization efficiency. In SSA, rice and maize crops yielded 24% and 69% more, respectively, when grown using SSNM compared to conventional farmer practices. Alternatively, yield increases of 11 and 4% were observed when comparing SSNM to the typical locally recommended fertilizer application method.

Yield monitoring in agriculture is an essential practice that provides farmers with valuable information about their crop production. It involves the use of advanced technologies, such as sensors and GPS systems, to measure and record crop yields during harvesting. Accurate yield data helps farmers make informed decisions regarding crop management, resource allocation, and future planning. By understanding the variations in yield across different areas of their fields, farmers can identify factors influencing yield variability, such as soil fertility, irrigation, or pest problems. This information enables them to adjust their practices accordingly, optimize inputs, and improve overall productivity. Yield monitoring allows farmers to assess the performance of different crop varieties, hybrids, or management practices. By comparing yield data from different fields or trials, farmers can identify the most productive areas or practices and replicate them in future seasons. It also helps in evaluating the effectiveness of specific treatments, such as new fertilizers, pesticides, or irrigation techniques, by quantifying their impact on crop yield.

Regarding precision agriculture yield monitoring is considered a fundamental component, which aims to maximize productivity while minimizing inputs and environmental impact. It provides the necessary data for site-specific management, allowing farmers to tailor their actions to the specific requirements of various areas within a field. By mapping yield variations, farmers can create prescription maps for variable rate application of inputs, such as fertilizers or seeds, optimizing their usage and reducing costs.

Accurate yield data is crucial for financial planning and analysis in agriculture. It allows farmers to estimate their production revenue, evaluate the profitability of different crops or fields, and make informed decisions regarding marketing, storage, or crop insurance. Yield data, combined with input cost information, helps farmers assess the return on investment (ROI) for different inputs or practices, facilitating better financial management.

When it comes to harvesting grain using combine harvesters, yield monitors can measure the weight of grain and the area harvested either load by load or area by area. This capability allows the operator to obtain real-time measurements of the total accumulated grain weight, harvested area, and average yield directly in the field. These data can be exported to a PC using numerous yield monitors, where they can be saved in nonvolatile memory for additional analysis or printing using specialized software packages or common word-processing and spreadsheet software. When linked to a global positioning system receiver, yield monitors can provide the necessary data needed to generate yield maps (Banus 2015). Yield mapping also helps decision-makers and farmers identify different productive zones within the field. This information enables them to evaluate whether using different planting populations will lead to higher revenue on their application. Farmers or producers use the yield map of the previous crop to estimate the fertilizer application rate, considering the nutrients depleted from the soil during the previous crop season (Das et al. 2018; Risius 2014; de Oliveira et al. 2019).

4 Agricultural Mechanization in Saudi Arabia

The Kingdom of Saudi Arabia is situated in the western part of the Asian continent and is the largest among the Arab countries, covering an approximate area of 2.3 million square kilometers. It shares borders with the Red Sea on the western side and the Persian Gulf on the eastern side. The population of the kingdom surpasses 28 million, with its capital city being Riyadh. The terrain of Saudi Arabia consists of large deserts, dry mountains, a central plateau, shrubs, and patches of fertile soil found in oases and basins. There are no permanent rivers or lakes, and the prevailing climate is typically desert, characterized by scorching daytime temperatures and very low temperatures at night. While rainfall is scarce, some destructive flash floods resulting from heavy rains have been witnessed in recent years (GFRAS 2023).

The Kingdom has only 1.6% of its total land area suitable for cultivation. As a result, the amount of land available for farming per person is very limited, estimated at 0.11 ha (World Bank 2018). This is regarded as one of the lowest rates worldwide. The economy of Saudi Arabia mainly depends on petroleum. However, the government has dedicated billions of dollars to enhance and modernize its agricultural industry, even though it is challenging due to the harsh desert conditions and limited water resources. Despite the significant costs, impressive progress has been achieved in agriculture within the country. Primary crops cultivated in Saudi Arabia include cereals like wheat, sorghum, barley, and millet. Moreover, a range of vegetables like tomatoes, watermelons, eggplants, potatoes, cucumbers, peppers, and onions are grown. Additionally, fruits such as dates, citrus fruits, mangoes, and grapes are cultivated as well. Finally, alfalfa and Rhodes are grown as fodder crops (GFRAS 2023).

According to the Agricultural Statistics Publication, fresh dairy products achieved self-sufficiency at a rate of 121% in Saudi Arabia in 2021, followed by table eggs at a rate of 112%, while fish reached 40%. Dates ranked first in plant resources, with a self-sufficiency rate of 118% and a local production of 1,565 thousand tons for 2021, while the self-sufficiency of tomatoes was 77% and onions was 52%. The total amount of agricultural imports for the year 2021 in Saudi Arabia was 20,037 thousand tons, with grains accounting for 42.5% of it. The total quantity of exports for the same year was 2,652 thousand tons, of which 23.5% was dairy products, eggs, natural honey (Agricultural Statistic Publication 2021).

Saudi Arabia has been classified as "water stress" and is expected to encounter a severe water scarcity by the year 2050 (Falkenmark et al. 2009). Baig et al. (2019) stated that the country's non-replenish aquifers are being rapidly depleted due to the adoption of unsustainable agricultural practices. This situation highlights the clear necessity for achieving self-sufficiency in food production.

Saudi Arabia possesses an annual groundwater availability of 3850 m^3, while surface water amounts to 1300 m^3 per year, which subject to variation based on annual rainfall. The anticipated sum of renewable water resources in Saudi Arabia amount to approximately 500 km^3, 340 km^3 of that amount is economically viable for extraction. It is estimated that Saudi Arabia's water consumption stands at an average of 24 billion cubic meters per year (Faridi and Sulphey 2019). As stated by Al-Hussayen (2007), the agricultural sector accounts for the majority of this consumption with 88%, then municipalities with 9% and the industrial sector with approximately 3%.

According to ESCAP (2013), it is projected that water availability will decrease in the future, while the global demand for water in agriculture is expected to increase by around 19% by 2050. As a result, in terms of food security, water scarcity is becoming a more significant determining factor than land scarcity, as stated by Brown and Funk

(2008). Considering the unique circumstances in Saudi Arabia, attaining sustainable food security requires the adoption of advanced agricultural technologies that can improve productivity, as stated by Fiaz et al. (2018).

Saudi Arabia is confronted with numerous challenges in guaranteeing food security because of its scarcity of water resources, extreme temperatures, and a growing population (Falkenmark et al. 2009 and Baig et al. 2019). The implementation of agricultural mechanization can aid in overcoming these obstacles by enhancing agricultural productivity, enhancing efficiency, and lowering labor expenses. Saudi Arabia needs to adopt a precision agriculture approach and practices such as site-specific nutrient management, variable rate irrigation, and precision planting can be adopted to enhance agricultural production and ensure food security.

Precision irrigation can effectively address the problem of water scarcity in Saudi Arabia of Saudi Arabia. Precision irrigation technology involves using irrigation moisture sensors that provide instantaneous data on moisture content of soil, thereby aiding management of irrigation decisions (Dubois et al. 2021). Several types of soil moisture sensors, including capacitance, resistance, and time-domain reflectometry (TDR) sensors, are available and can be installed in the field. These sensors monitor the moisture content of soil over time by connecting to a data logger. The information collected from these soil moisture sensors, along with weather forecast data and evapotranspiration models, is utilized in predictive irrigation systems to anticipate future soil moisture levels and help make decisions regarding irrigation management (Yartu et al. 2022). This involves analyzing the data using machine learning algorithms such as linear regression, logistic regression, decision trees, random forest, and neural networks. After analyzing the aforementioned data and considering factors like weather conditions, crop growth stage, and soil characteristics, recommendations are provided regarding irrigation scheduling, the appropriate amount of water to apply, and the intervals at which irrigation should occur. This precision irrigation system can effectively apply water as needed, thus improving irrigation efficiency and addressing the issue of water scarcity. In general, adopting modern technologies and investing in agricultural infrastructure to enhance agricultural productivity and ensure a steady food supply for its population can help Saudi Arabia improve food security and bolster its economy through agricultural mechanization.

5 Conclusion and Prospects

The Kingdom of Saudi Arabia possesses the second-largest proven petroleum reserves and the fourth-largest measured natural gas reserves. Currently, Saudi Arabia holds the position of the world's largest exporter of petroleum, earning it the title of a petrostate in Western media. In 2016, the Saudi government introduced the Saudi Vision 2030 program with the goal of diminishing reliance on oil and expanding the diversity of its economic resources. As a result, there has been growth in the industrial sector, which has had an impact on the availability of agricultural labor. To address the issue of labor scarcity caused by industrialization, the Kingdom should enhance the level of agricultural mechanization in order to achieve food security. Considering the limited arable land in relation to the total land area, implementing precision agriculture methods and practices like variable rate seeding and site-specific nutrient management would be necessary to boost agricultural production and ensure food security. Additionally, the Kingdom of Saudi Arabia is also confronted with the challenge of water scarcity, which can be mitigated through the adoption of precision irrigation techniques.

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Chapter 15
Transportation Infrastructure and Food Security in Saudi Arabia

Mutasim Mekki Elrasheed

Abstract Transportation is one of the main drivers of food security. Saudi Arabia has given special attention to the transportation sector and established the Ministry of Transportation (MOT) to take responsibility for its supervision and development. It has also given special attention to food security in its 2030 Vision and assigned the role of its management to the Ministry of Environment, Water and Agriculture. This chapter aimed to shed light on the transportation infrastructure and food security in Saudi Arabia. It is evidence that transportation is crucial for food availability and accessibility being affected by both the supply and demand side of goods. On the supply side, good transportation increases agricultural productivity and economic growth, however; on the demand side, it improves consumers' income and creates job opportunities. It is also clear that the Kingdom has a well-established transportation system and logistics services that are widely spread and strongly connected with international markets. This strong transportation infrastructure coupled with sound measures and policy has reflected in the Kingdom's ability to sustain its food security even during adverse conditions of COVID-19, as the country ranked first in terms of global food security indicators during the pandemic time.

Keywords Air transportation · Food accessibility · Food availability · Logistics services · Maritime transportation · Road transportation

1 Introduction

Infrastructure is the main driver of economic growth. It plays a significant role in global welfare, growth, and development, by improving productivity, linking regions, and ensuring food security. The Global Infrastructure Investor Association (2023) estimated that 3.3 trillion USD in infrastructure capital investment is required annually for worldwide economic growth. It is stressed that investing roughly 5.1 trillion

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USD, 7.5 trillion USD, and 11.4 trillion USD, in the rail, water, and roads sectors, is necessary to meet the projected global growth. However, the Global Outlook (2023) predicted that global investment needs, current investment trends, and investment gaps were at 94 trillion USD, 79 trillion USD, and 15 trillion USD, respectively. Similarly, the Quality Infrastructure Investment Partnership (2021) of the World Bank Group has argued that G20 QII has identified six principles to ensure sustainable investment. These include maximizing the positive impact of infrastructure for sustainable growth and development, raising economic efficiency by taking into consideration life-cycle costs, integrating environmental and social considerations into infrastructure investment, building resilience against natural disasters, and strengthening infrastructure governance. However, it is important to note that the G20 QII principles have been developed from the G7 QII Principles. The World Economic Forum (2019) claimed that approximately 14% of the world's GDP is spent on infrastructure.

Infrastructure is a critical factor for maintaining food security. In the Kingdom of Saudi Arabia (KSA), the Ministry of Environment, Water and Agriculture (MEWA) has developed a comprehensive food security strategy and assigned its implementation and supervision to the General Authority for Food Security (GFSA), formerly known as the Saudi Grains Authority (SAGO) (GFSA 2021). Furthermore, the Kingdom has established the Commodity Abundance Committee (CAC) to guarantee the availability, affordability, and stability of food products. The CAC coordinates with other Saudi governmental and non-governmental bodies, such as the Saudi Agricultural Development Fund, the Saudi Agricultural and Livestock Investment Company (SALIC), and MEWA to ensure a stable food supply. The committee intervenes directly and indirectly to sustain a stable strategic food reserve. It intervenes directly to purchase food items when the strategic reserve reaches critical limits and indirectly through the provision of support in terms of direct funds or aid. In this regard, it is important to mention that Saudi Arabia is a water-scarce country thus, it relies on three main sources to maintain its strategic food Reserve: domestic production, abroad investment, and imports.

Based on the importance of transportation infrastructure in ensuring food security, the objective of this chapter is to shed light on the transportation infrastructure and food security in Saudi Arabia.

The chapter provides an overview of the Saudi Arabian economy, the basic concepts of infrastructure and food security, transportation infrastructure, and their impact on food security in Saudi Arabia, and finally draws conclusions and outlines prospects for the future.

2 Infrastructure and Food Security

2.1 Infrastructure: Meaning and Classification

Before moving forward, it is crucial to gain a clear understanding of the concept and categories of infrastructure. The term "infrastructure" is derived from two Latin words, "infra" meaning below or underlying, and "structure" referring to the basic physical and organizational structures and facilities necessary for the efficient operation of a society or enterprise, such as transportation, roads, power supplies, schools, and more. Transport infrastructure, for example, encompasses various fixed assets like roads, railways, train stations, ports, and airports, along with the corresponding service processes that build the physical assets and support transportation. It also reflects societal concerns regarding mobility and the supply of goods (Große 2023). Moreover, infrastructure can be categorized into three groups, according to Buhr (2003): institutional, personal, and material. The first category refers to customary practices, rules, and facilities that ensure the effective implementation of infrastructure. The second category deals with human capital, while the third one deals with capital goods such as transportation, telecommunications, and energy. In contrast, Tabasam (2019) classified infrastructure into economic, social, and institutional components, citing Stilwell and Atkinson's (1998) work. Economic infrastructure includes elements necessary for economic development, such as utilities. Social infrastructure or soft infrastructure addresses community welfare, including housing, education, and health. Finally, institutional infrastructure involves the development of instructional structures (such as agricultural institutions). The World Economic Forum (2012) emphasizes the importance of commercial infrastructure, which is designed specifically for commercial purposes. However, the focus of this chapter is the transport infrastructure.

2.2 Overview of Food Security

Food security refers to the situation in which all people at all times have access to sufficient, safe, and nutritious food that meets their dietary preferences and needs for a healthy and productive life (FAO 1996). According to the World Bank in 2023, there are four dimensions of food security: physical availability of food, economic and physical access to food, food utilization, and stability. The first dimension, the physical availability of food, focuses on the supply side of food security, which includes food production, stock, and trade. On the other hand, the second dimension, economic and physical access to food, concentrates on the demand side of food security, which can be achieved through appropriate policies that focus on income, expenditure, markets, and prices. The third dimension, food utilization, centers on the effective use of available and accessible food to meet individual nutritional requirements. Finally, the fourth dimension, stability, is concerned with the sustainability of the other dimensions of food security over time, as outlined by Ahmed et al. (2023).

2.3 Infrastructure and Food Security

The transport sector is a critical factor in ensuring food security as it affects food availability and household food accessibility. Moreover, transportation is known to drive economic growth by minimizing the production and transportation expenses of goods and services, enhancing the productivity of input factors, and indirectly creating positive externalities.

Food production relies on various inputs that need to be available at the right time, place, and in the correct quantities. Evidence from the region demonstrates that investments in physical infrastructure can enhance productivity by reducing transportation costs and uncertainties in obtaining necessary inputs. A prime example can be seen in Colombia, where rural road building and maintenance programs improved farmers' access to fertilizers, insecticides, and machinery, leading to a 62% increase in agricultural productivity. Additionally, these efforts increased sales probability by 5% and production value by 15% (Pinto et al. 2023). Baek's research (2016) indicated that an increase in the number of bus-equivalent vehicles per 10 thousand people reduces the likelihood of households experiencing food insecurity by 1.6%. He concluded that the impacts of public transportation are particularly noticeable among poor families. In summary, the availability of sufficient quantities of agricultural inputs at the right time and place is crucial in food production. Improvements in physical infrastructure can enhance local income and reduce poverty and food insecurity. An illustration of this can be seen in Peru, where investing in rural roads generated job opportunities and reduced extreme poverty and unmet needs in neighboring communities by up to 14% and 7%, respectively (Baek 2016).

In 2006, Pinstrup-Andersen and Shimokawa stated that poor road infrastructure conditions lead to poorly functioning markets. This ultimately affects the food supplies and subsequently the food security of the country. Additionally, in 2023, Pinto claimed that poor infrastructure and logistics services affect food prices and reduce producers' competitiveness in the marketplace. Even with sufficient income, households living in regions with poor access to infrastructure have a higher probability of experiencing food insecurity. Therefore, funding transportation infrastructure is critical in safeguarding the food security of millions of people worldwide who may go hungry.

Transportation affects economic growth by influencing both supply and demand. Therefore, investing in transportation and logistics services directly affects growth, as they serve as essential factors in the production of goods and services and the creation of job opportunities. The cost of transportation is directly related to the quality of roads and their accessibility. Poor road conditions and limited access to roads increase transportation costs to market centers and limit farmers' access to schools, hospitals, cultural amenities, and economic opportunities, thus encouraging them to migrate to urban centers. To improve households' physical food accessibility, it is important to improve regional market integration, increase transportation accessibility, and develop market infrastructure (Kulikov and Minakov, 2019).

In 2015, the Kingdom released an ambitious vision (Vision 2030) with the aims of reducing its sole dependency on oil, diversifying its economy, developing all sectors, achieving food security, improving citizen welfare, and other goals. To achieve these goals, the Kingdom has launched many initiatives and development programs. With regard to food security, Althumiri et al. (2021) argues that Saudi Arabia has a well-developed plan for sustaining its food supply chain, in which it is implementing improved systems to optimize goods movement, achieve efficient inventory management, develop a more efficient transportation system and logistics services, and improve the workforce's ability through specialized communication and training programs. Additionally, the Kingdom has made agreements with partner countries in which it plans to invest in its agricultural sector.

MEWA has implemented significant measures to develop its agricultural sector and maintain its food security. These measures have led to improvements in food security indicators, including the enhancement of consumption systems, reductions in food loss and waste, attainment of high rates of self-sufficiency for numerous strategic food commodities, and improvement in the efficiency of agricultural and food systems (MEWA 2021).

Saudi Arabia has well-developed transportation and other infrastructure systems. It has also implemented sound measures and precautions to sustain its food security. These infrastructure, measures, and precautions have resulted in improving the Kingdom's food security situation even during adverse conditions. For instance, Alsuwailem et al. (2022) argued that during COVID-19, the food security situation in the Kingdom was evident in the supply chains and its consequences on demand and transportation shortages. However, the overall distribution of items was not affected, and likewise, the overall distribution of states from which KSA imports its items did not suffer from a significant impact. In this regard, SPA (2021) argued that KSA achieved the first global position in terms of the Global Food Security Index (GFSI) and its sub-indicators during the COVID-19 pandemic time. The GFSI covers issues such as food security/insecurity and their causes, nutritional quality, and diversification, in addition to food safety. During the same period, the Kingdom moved steps ahead in the global indicator measures, occupying the eighth and ninth positions, respectively, in the self-sufficiency of food supply index and the growth of grain and vegetable production, in comparison to 2019.

3 Overview of the Saudi Arabia Economy

The KSA is the largest country in the Arab world, with an area of approximately two million square kilometers, according to GASTAT in 2023a. The Kingdom has a wealth of natural resources, including natural gas, iron ore, gold, and copper, as

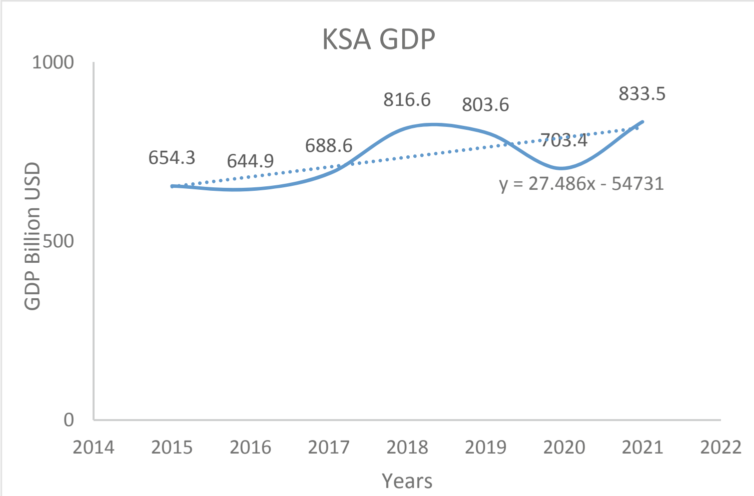

Fig. 1 Saudis Gross Domestic Product (GDP) for the period 2015–2021 (Billion USD). *Source* Calculated by the author based on data from World Bank (2023a, b)

reported by OPEC in 2023a. It also has diverse climatic conditions and a considerable population of 32.18 million heads with Saudi constituting more than 58%, as stated by GASTAT in 2023b. The country ranks second globally in terms of proven petroleum reserves, which estimated are at 267 billion barrels and constitute about 16.2% of the global reserves, according to Worldometers (2021). It also holds the second position globally in terms of oil production, producing about 9.5 million barrels per day, as reported by OPEC (2023b). The Gross Domestic Product (GDP) of the Kingdom is increasing over time, with an annual growth rate of 27.5 billion USD per annum over the last five years (Fig. 1). According to IMD (2023), the KSA ranks 17th in the world as the top economy in terms of real growth domestic products, reaching 833.54 billion USD in 2021. In fact, the KSA economy is considered the fastest-growing economy in 2022, with its real GDP growing by about 8.7% compared to 2021, as reported by GASTAT (2023b). These figures indicate that the Kingdom's contribution to the world economy is 0.37%, according to Trading Economics (2023).

4 Saudi Transportation Infrastructure

The transportation sector consists of roads, air travel, maritime transport, and logistics services. It is important to note that the Ministry of Transport and Logistic Services (MOT) is the governing entity responsible for overseeing the transportation sector.

The Saudi government has prioritized the transportation sector, beginning in 1953 when the Ministry of Communications was established to supervise all aspects of transportation, including roads, railways, and ports. In 1975, the General Corporation for Ports and the General Corporation for Railways was created as part of a broader restructuring of state ministries. Since that time, the Ministry of Communications is responsible for designing, constructing, and maintaining roads and bridges, but later on, a specialized agency was created to take care of planning and supervising land and sea transport, coordinating between different means of transport, regulating transport sectors, and issuing necessary licenses (MOT 2023a). The ministry's name was changed to the Ministry of Transport in 2014 and to the Ministry of Transport and Logistics Services in 2021. In addition to its responsibilities in other types of transport, nowadays the Ministry also has supervisory authority over the air transport sector, including airports and air navigation services. It is noteworthy that the Kingdom has a total of 27 airports, 5 of which are international, 12 regional, and 10 domestic, all of which provide a full range of services to air travelers (MOT 2023a).

4.1 Vision, Mission, and Objectives

The Ministry of Transport and Logistic Services aims to become a sustainable transportation and logistics services sector that explores the future and enables national capabilities to consolidate the Kingdom's position as a global logistics center and a model for integrated mobility (MOT 2023a). Its mission is to achieve the integration between land, maritime, and air transport sectors to meet the Kingdom's needs by improving safety levels, rationalizing energy, and enhancing operational and performance efficiency to provide efficient services to all beneficiaries (https://mot.gov.sa/en/AboutUs/Pages/Mission.aspx). Whereas, the objectives, according to MOT (2023a), are as follows:

- Improve land, sea, and air transport services by providing opportunities for the private sector to contribute to the transfer of global expertise and experience, which will stimulate the development of the national carrier.
- Expand the application of smart transportation systems on roads, sea, and air transport to improve safety levels and increase the effectiveness of various means of transportation.
- Enact legislation regulating transport and support the private sector in establishing and operating both transport stations for passengers and goods and logistic growth centers.
- Raise performance efficiency and enhance the quality and transparency standards in the Ministry's activities through automation of business, development, clarification, and dissemination of procedures through appropriate communication channels, and raising the efficiency of the Ministry's workforce.
- Expand the applications of electronic systems in transport sectors toward achieving a complete transformation of electronic transactions.
- Expand sources of finance for the construction and maintenance of transport facilities in a way that enhances the role of the private sector and its participation in financing and operating the transport sector.

- Unify KSA transport sectors under one umbrella to reduce expenses, increase revenues, enhance operational and performance efficiency, and standardize procedures.

4.2 Role of the Ministry of Transport and Logistic Services (MOT)

The MOT works to study, design, and implement roadworks while ensuring their proper maintenance. Additionally, the Ministry plays a crucial role in coordinating the transport and logistics system and acts as the regulator for the daily planning and execution of KSA land, sea, and air transport services. The MOT aims to connect the Kingdom to the outside world and become a global logistics center for three continents. The Ministry strives to provide high-quality services for all KSA beneficiaries and develop the transport and logistics sector through the harmonization of land, sea, and air transport sectors. The MOT follows a clear framework and methodology based on the Kingdom's Vision 2030 to contribute to the improvement of the KSA's economic development and global competitiveness as the transportation and logistics sector is the foundation of the KSA economy and plays a crucial role in sustainable development and achieving developmental strategy objectives. However, the success of this sector relies primarily on providing roads and different means of transportation infrastructure. In this regard, the MOT has implemented various road safety initiatives aimed at reducing accidents and enhancing safety measures. Additionally, the Ministry is working to reduce the cost of the road life cycle and improve its performance while generating revenues from road assets and preparing privatization programs. To meet current and future requirements, the Ministry has adopted an organizational structure that aligns with the Kingdom's Vision 2030 and created new agencies and departments accordingly. The Ministry has empowered general managers of MOT branches to supervise road projects and established a department for joint services to facilitate an integrated coordination role, eliminating centralization in work.

4.3 Transport and Logistics Services Sectors in the KSA

The transport and logistics system in the KSA comprises the following sectors: roads, air transport, land transport and railways, maritime transport, and logistics services.

4.3.1 The Roads Sector

The national strategy for transportation and logistics services places special emphasis on the road sector, as it plays a vital role in the development of other sectors. The importance of this sector has increased tremendously as the Kingdom has occupied a top position in global road connectivity (MOT 2023c). Saudi Arabia has recently expanded and modernized its road networks and national highways to meet the needs of its growing population, urbanization, economic growth, and increasing car usage. According to the MOT, the road network comprises over 75 thousand km, connecting various cities, while the length of highways in operation is over five thousand km (Fig. 2). Additionally, MOT is developing secondary roads spanning 49 thousand km, aiming to transform them into dual roads (MOT 2023c).

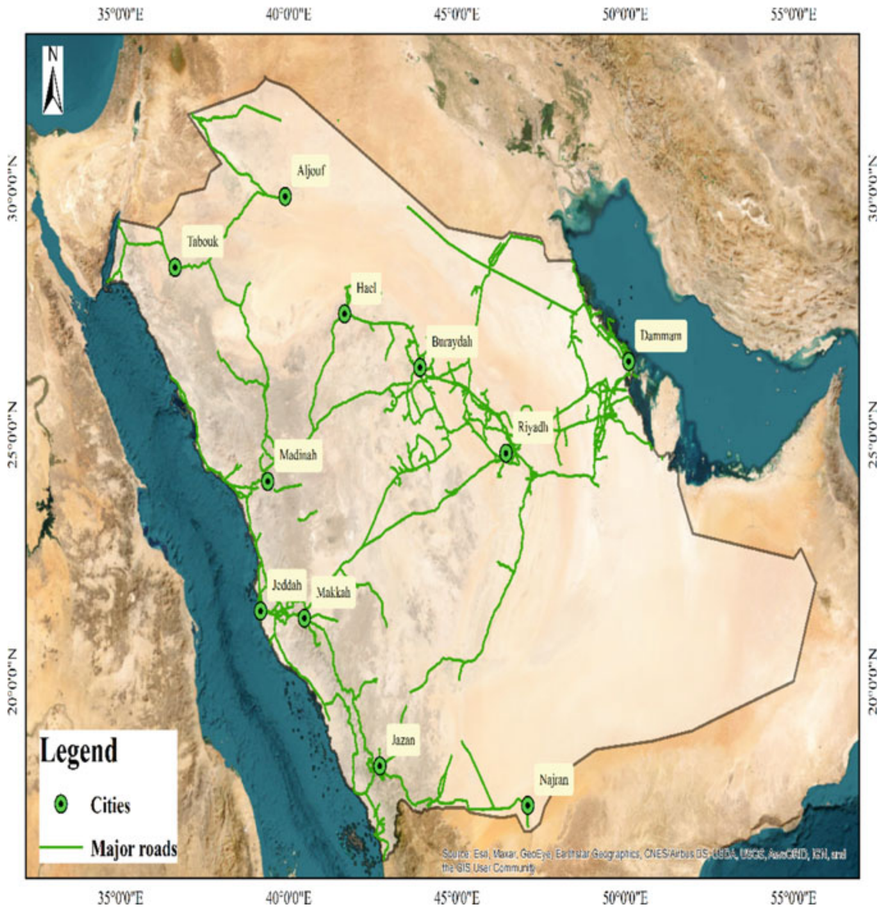

Fig. 2 Saudi Arabia Major InterCitys Roads Map. *Source* constructed by the author based on the Esn. Maxer. Geoeye. Earthstar Geographics, CNES/Airbus the SIS User Community

The Aims of the KSA Strategy for Transport and Logistics Services with Respect to the Road Sector

According to the MOT (2023c), the objectives of the road sector are to: enhance road safety for users and establish efficient transportation hubs via a privatization program, improve the national program for road quality and safety, form a National Center for Transport Safety, and develop new roads to improve connectivity between urban and rural centers. The strategy also seeks to decrease traffic congestion in big towns such as Riyadh and Jeddah and strengthen regional road connections with neighboring nations such as Bahrain and Egypt through infrastructure upgrades. Additionally, it plans to incorporate smart city technologies into road infrastructure planning and increase private sector participation in road development projects. Other objectives of this strategy are to upgrade roads for integrated transportation, facilitate the movement of goods into and outside the Kingdom, and provide secure supply chain solutions to handle emergencies. It also intends to establish a "Future Transportation" center to foster the adoption of new transportation technologies and logistics services in the Kingdom. This initiative aims to establish a sustainable and future-oriented approach to enable technical innovations in the transport and logistics sector through its specialized unit.

4.3.2 Air Transportation Sector

The national strategy for transportation and logistics services contributes to the development of the air transportation sector to make Saudi Arabia a hub for connecting three continents, with 29 airports linked to 149 international destinations, moreover, the sector supports 594 thousand job opportunities (MOT 2023d).

Objectives of the KSA Strategy for Transport and Logistics Services with Respect to the Air Transportation Sector

The MOT has outlined its objectives for the air transportation sector in its 2023d report. These objectives include improving airport infrastructure and facilities, increasing accessibility to airport transportation options, and increasing cargo capacity to 4.5 million tons by 2030. The aviation sector's goal of carrying 330 million passengers by 2030 is also a target. Furthermore, promoting partnerships between the public and private sectors and training Saudi employees to become leaders in the sector are important goals. Increasing the number of international airlines using the Kingdom's airports and increasing airports' capacity to handle large numbers of pilgrims annually (30 million) are also important. The MOT aims to create a fair and competitive sector for airline operators and consumers. Establishing a new national air carrier and airport in Riyadh and enhancing the competitiveness of national companies are other objectives. Moreover, the MOT aims to increase connectivity to over 250 destinations, both domestically and internationally. The

Logistics Platforms Initiative, which began with Al-Khumra Logistics Zone and the Model Cargo Village at King Khalid Airport, is also a key initiative. The MOT plans to build partnerships with the private sector to manage airports after successful privatization, such as those in Riyadh and Dammam. The Kingdom has significant development plans for airports, roads, and ports, and it aims to benefit from investment opportunities with funds and investment entities. Encouraging private sector cooperation in developing transportation infrastructure in the Kingdom, including the operation of ports, airports, and supply chains, is also an important objective. The MOT seeks public–private partnerships to fund various schemes, such as the full privatization of state-owned transport facilities, and to take advantage of the Kingdom's geographical location to become a global logistics center. The focus of the civil aviation strategy is to create a conducive global investment environment and to make the KSA aviation sector a pioneer regionally and globally. This will support the Saudi national economy and achieve development regional and worldwide goals.

4.3.3 Land Transport Sector

The aim of the National Strategy for Transport and Logistics Services is to advance the land transportation industry in a manner that bolsters job opportunities for citizens, elevates the quality of life, and enhances multiple modes of transportation (MOT 2023e).

Objectives of the KSA National Strategy for Transport and Logistics Services - Land Transportation Sector

The Ministry of Transportation's 2023e report states that the objectives for the land transportation sector are to implement plans to reduce the environmental impact of using different means of land transportation, improve non-oil revenues, and monitor compliance with the implementation of public transport networks in cities. This monitoring will prioritize factors like population density, average household income, and the percentage of private vehicle ownership to ensure the desired operational objectives are achieved.

4.3.4 The Railway Sector

The Kingdom's national strategy for transport and logistics services aims to develop the railways sector by improving its efficiency and achieving its integration with all transport sectors in the Kingdom. The total length of the railway network in the Kingdom is 5.33 thousand km carrying about 3 million passengers annually (MOT 2023g).

Objectives of the KSA National Strategy for Transport and Logistics Services – Railways Transportation Sector

The objectives of the National Strategy for Transport and Logistics Services for the railway's transportation sector are to develop railway/interconnection services; update existing rail cars with up-to-date types; improve passenger experience; enhance diversity and integration between all transportation sectors; in addition, use smart technologies to improve the passenger journey (MOT 2023g). Moreover, it plans to increase the engagement of the private sector, establish and operate an effective and safe railway infrastructure to reduce energy consumption rates, reduce accident rates, and provide distinguished transportation services that contribute to the social and economic development and growth of the Kingdom (MOT 2023g). Furthermore, it aims to open the railway market to new operators over the next few years, provide information and communication technology solutions and develop a smart railway system; provide vocational and technical training and contribute to the research and development of the sector, look for innovations in the field such as high-speed trains, and "Hyper Lube" technology. It also plans to enhance traffic safety in general and reduce carbon emissions from other modes of transportation; promote the opportunities for public–private partnership for railway infrastructure, encourage global investors, interconnect all parts of the Kingdom through a network of trains, improve transportation efficiency and enhance the competitiveness of Saudi commodities by reducing transportation costs (MOT 2023g). In addition, increase the attractiveness of the Saudi market for individual investors and facilitate the movement and transportation of goods, and connect the special economic zones in the Kingdom and facilitate movement between them.

4.3.5 Maritime Transport Sector

The Saudi strategy for transportation aims to enhance the maritime sector by implementing various development projects that diversify sources of income, improve maritime infrastructure, and strengthen interconnection with other transport sectors in KSA. This is crucial, given that over 75% of non-oil maritime trade passes through the Kingdom. Recently, the Kingdom has greatly expanded its maritime network capacity to accommodate up to 9 million containers and receive 13.0 thousand ships annually. Notably, the Kingdom has 10 major ports for non-oil trade and 240 berths strategically located at the crossroads of shipping routes between East and West. In addition, the Kingdom plans to receive cruise passengers along the Red Sea coast by 2023 (MOT 2023f).

Objectives of the KSA National Strategy for Transport and Logistics Services—Maritime Sector

In 2023, the Ministry of Transport (MOT) established objectives for the land transportation sector. These objectives aim to increase the capacity of maritime ports to 40 million containers at Red Sea ports, improve trade facilitation processes for marine commodities, enhance integration with other modes of transportation such as air, road, and rail transport, and construct passenger terminals at ports to serve international cruise passengers. Additionally, the objectives aim to increase the depth of ports to allow large ships to dock, implement smart technologies like automation throughout ports and logistics infrastructure, lessen the negative impact of maritime transport on the marine environment, develop productive, safe, and environmentally friendly facilities in the Kingdom's ports to enhance economic growth and keep pace with global developments. Moreover, the objectives aim to contribute to the giant industrial plans and create an attractive environment for investment, enhance the capacity of Red Sea ports to 40 million containers, and link all industrial sectors, including geographical connections to ports and airports. Furthermore, the objectives aim to enhance navigation line numbers and create new lines for regional and international ports, establish a vital role in the growth of tourism and entertainment sectors through the development of the ports sector, and attract investments through privatizations and partnerships with the private sector. Moreover, it aims to increase the competitiveness of Saudi products by reducing transportation and export costs, expanding port capacities at King Abdulaziz Port, Duba Port, King Abdullah Port, and Jeddah Islamic Port, as well as improving operational processes. Moreover, they aim to establish the Kingdom as a major hub for global projects that target to improve global trade, develop ports, particularly in the Red Sea region, to take advantage of the great tourism potential in the area, increase marine tourism and entertainment with local and international cruise trips. Additionally, they aim to improve the capacity of container terminals at King Abdulaziz Port in Dammam by over 120 percent to 7.5 million containers per annum. It is noteworthy that this port is connected by rail to the dry port in Riyadh, providing an integrated link for shipping goods at reasonable costs with the transportation network that links ports and railways. Moreover, they aim to launch a port network and shipping lines to attract and facilitate international trade.

4.3.6 The Logistics Services

The logistics sector is a modern aspect of transportation systems in which the Saudi strategy for transportation and logistics services seeks to benefit from the strategic geographical location in the international trade line, being located between the Arabian Gulf and the Red Sea. Additionally, the Kingdom has the largest economy in the Gulf Countries, contributing roughly 38% of the gross domestic product and accommodating 21% of the region's population. Moreover, in 2019, the Kingdom boasted an increase of 72 ranks in the trade across border index (MOT 2023f). Additionally, about one-third of the world's oil exports pass through the Arabian Gulf while around 13% of the world's trade flows through the Red Sea. It is worth noting that the transportation system has established various logistical areas, including the Al-Khumra Logistics Zone (MOT 2023f).

Objectives of the KSA National Strategy for Transport and Logistics Services – Logistic Services

The objectives of the KSA Strategy for Transport and Logistics Services in the logistics services sector are to improve integration with transportation sectors by strengthening the links between sea, air, road, and rail transport to enhance cargo and freight services. The strategy includes embedding smart technologies, such as automation, across ports and logistics infrastructure. The Kingdom's ranking on the logistics services performance index has advanced from 55th to the top ten, ensuring its regional leadership. The strategy aims to support the success of classifying three Saudi cities among the top 100 best cities in the world. With developed ports and railway connections, the Kingdom will be a major hub for all global projects that aim to develop trade between East and West. Numerous reforms and initiatives in the logistics sector in Saudi Arabia support the Kingdom's position as one of the fastest countries in the world to decide and implement reforms. Linking with neighboring countries increases the attractiveness of the Saudi market for individual investors and facilitates the movement and transportation of goods. The strategy aims to improve procedures and legislation for licensing logistics services and encourage local industry initiatives and attract new industrial investors by improving logistics services to lessen the cost of transportation and storing of Saudi-origin goods. The strategy also includes global logistics platforms for maritime navigation with two global axes for aviation. The plan aims to develop 69 logistical platforms, grouped into 27 logistics areas, 8 areas at land ports, and 9 areas at truck parking to ensure optimal efficiency. Additionally, three logistics areas at the airports of the cities of Riyadh, Jeddah, and Dammam are to be developed to handle 4–5 million tons annually of airfreight, and three logistics areas in the ports of Jeddah, King Abdullah, and King Abdulaziz, are to be developed to handle 14 million containers, playing a major role in enabling export, import, and re-export.

5 Conclusion and Prospects

The transportation system is one of the main actors for the sustainability of food security in the world, through improving food availability, accessibility, agricultural productivity, and job creation. The purpose of this chapter is to provide information about transportation infrastructure and food security in the KSA. It is evident that the Kingdom is a global leader in terms of road networks, with intercity roads covering over 75 thousand km, operating highways covering over 5 thousand km, and around 49 thousand km of roads planned to be dual roads. Moreover, the Kingdom has developed its maritime network capacity, with 10 ports for non-oil goods and 240 berths, allowing for the transport and receipt of 9 million containers and 13, thousand ships annually. There are also 29 airports in the Kingdom linked to 149 international destinations, providing 594, thousand job opportunities, as well as 5,330 railways network km with an annual carry capacity of about 3 million passengers and various logistical areas, including the Al-Khumra Logistics Zone. It is also evidence that the Kingdom works hard to become a global logistics center for the three continents. In doing so, it adopts a clear framework and methodology to realize Vision 2030 that will contribute to the improvement of economic development and sustainability of food security. In this context, it is noteworthy to mention that the issue of sustainable food security is strongly emphasized in Vision 2030, with the Ministry of Environment, Water and Agriculture (MEWA) taking a supervisory role.

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Chapter 16
Implications of Population Growth on Food Security in Saudi Arabia

Abeer Abdulla Kinawy and Rehab Said Ahmed

Abstract Food security is currently an important priority for Saudi Arabia, especially since the country imports about 70–80% of its basic food commodity needs, constituting a threat to strategic food security and financial situation, considering the steady decline in oil prices. Saudi Arabia witness about 1.7% population growth rate and to cope with the increased demand for food the country adopted many agricultural policies to secure food. Development plans have given special attention to the population issue, in its various dimensions, and have been keen on rationalizing and directing population trends to serve development goals, programs and projects, raise the standard of living of citizens and improve their quality of life. This is accomplished by increasing job opportunities for citizens and offering high-quality public services, all while continuing to support low-income groups. This chapter focuses on food security and population growth in Saudi Arabia emphasizing the Characteristics of the demographic situation in Saudi Arabia, Problems and difficulties of the standard of living and quality of life. It also shed light on the Development strategy and future vision, in addition to the current and prospects for food Security in the Saudi Arabia.

Keywords Development plans · Food security · Quality of life · Population growth

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1 Introduction

Food security is currently an important priority for the Saudi Arabia, especially since the Saudi Arabia imports about 70–80% of its basic food commodity needs, constituting a threat to strategic food security and puta financial burden, considering the steady decline in oil prices. During the last three decades, many indicators that show the beginning of a food crisis, as the average food prices rose during the past decade by about 30–40%, which led to a sudden inflation in food prices, and an increase in demand for food is expected. To cope with the increased demand for food resulting from the high rate of population growth, Saudi Arabia has adopted many agricultural policies to secure food. For example, in the eighties of the last century, Saudi Arabia adopted a policy of supporting local agriculture, especially wheat, and barley, to achieve food security. Despite the success of that policy, it has negative effects on water security and depletion of the non-renewable groundwater. This led to the launch of “King Abdullah’s initiative for agricultural investment abroad” to achieve food security and preserve non-renewable water resources. It is important to note that the development plans have taken into consideration different aspects of the population issue, as they were keen to rationalize and direct population trends to serve development goals, programs and projects that raise the standard of living for citizens; Furthermore, it aims to enhance the overall well-being of individuals and foster a better standard of living. The Ninth Development Plan aims to continue the efforts of the Eighth Development Plan through adopting effective population policies. These population policies aim to deal efficiently with population growth factors and their geographical distribution, raise the standard of living and improve the quality of life via providing more job opportunities for citizens and high-quality public services care for low-income groups (Ministry of Economy and Planning 2000).This chapter aims to analyze the current situation of the Saudi population and the standard of living giving consideration to the developments that occurred during the Eighth Development Plan and highlighting the issues and challenges that must be faced during the Ninth Development Plan. It was also aimed to illuminate the future vision for improving the conditions of the population as well as their standard of living and quality of life. This would be achieved through reviewing the overall objectives of the development plans and the policies associated with them, which are related to the population and their impact on indicators of food security.

2 Characteristics of the Demographic Situation

2.1 Population Size

The overall population of Saudi Arabia increased from approximately 7 million people in 1974 to around 16.9 million in 1992 and then to about 22.56 million in 2004. By 2009, the estimated total population reached 26.66 million. In terms of

Table 1 Population development in Saudi Arabia since 2004 (million people)

Year	Saudi	Non-Saudi	Total
2004	16.44	6.12	22.56
2005	16.85	6.48	23.33
2006	17.27	6.85	24.12
2007	17.69	7.25	24.94
2008	18.11	7.67	25.79
2009	18.54	8.12	26.66
2010	18.97	8.59	27.56
2011	19.40	8.97	28.38
2012	19.84	9.36	29.20
2013	20.27	9.72	29.99
2014	20.70	10.07	30.77
2015	21.12	10.40	31.52
2016	20.06	11.68	31.74
2017	20.41	12.14	32.55
2018	20.77	12.64	33.41
2019	21.11	13.10	34.21

Source General Authority for Statistics (2023a) Statistical Yearbook (2004–2019)

Saudi citizens, their number grew from roughly 6.2 million in 1975 to approximately 12.3 million in 1992, and then to about 18.5 million in 2009. As for the non-Saudi population, their number went up from around 0.8 million to about 4.6 million in 1975, and to approximately 6.14 million in 1992, and around 8.12 million in 2009 (according to Table1). A report issued by the General Authority for Statistics (2021) show that the population of Saudi Arabia exceeded the level of 35 million people by the end of the first half of the year 2020.

The results of the demographic characteristics survey in 2017 showed that the population of Saudi Arabia was approximately 32 million, compared to 31 million in the 2016 demographic survey. This indicates an average annual growth rate of 2.52%. (General Authority for Statistics 2020b). The estimated population of Saudi Arabia in 2020 is 34.81 million, with an estimated population growth rate of about 1.73% compared to 2019, when it was 34.22 million. Therefore, the population in 2020 increased by about 0.59 million people compared to the previous year. This increase amounts to about 7.73 million people over a period of 10 years, since the last official census in 2020. (General Authority for Statistics 2021).

The General Authority for Statistics has revised the numbers of Saudi Arabia's historical population for the period of 2010–2021. Accordingly, the population summary report of Saudi Census 2022, revealed that the total number of population in Saudi Arabia was 32.175 in 2022, which is higher than that of 2010 by 34.2%, with

Saudi and Non-Saudi population constitute about 58%, 42% respectively (General Authority for Statistics 2023b).

2.2 Population Growth

Based on the findings from the general population and housing censuses, the rate of population growth was calculated to be approximately 4.9% per year on average between 1982 and 1992. However, this growth rate declined to approximately 2.4% by the year 2004. In the same line, the Saudi population growth rate decreased to about 3.9% on average annually, while non-Saudis decreased to about 2.5% during the same period, as the population growth rate witnessed a significant decline to 1.8% and 1.7% in 2018 and 2019 respectively.

2.3 Fertility

Saudi Arabia is globally classified as an average fertility rate country. Statistics have shown a significant decrease in the total fertility rate, dropping from over seven live births /woman of childbearing age to approximately 3.3 live births per woman of childbearing age in 2007. This accelerated decline is due to the decline in the total fertility rate among women of almost all age groups, especially those aged less than 30 years, due to the high marriage age, as well as the high level of family education and culture. Table 2 depicts that the fertility rate for Saudi Arabia is 2.175, 2.208, 2.241 and 2.274 births per woman in years 2023, 2022, 2021, 2020 respectively, expressing accordingly a decline of 1.49%, 1.47%, 1.45% and 1.43% (World Bank 2023).

2.4 Deaths

Saudi Arabia has seen a significant improvement in mortality rates over the years. In 1980, the crude death rate for the Saudi population dropped from approximately 15 deaths per thousand to about 12.5 deaths per thousand. By 2008, it had decreased even further to 3.8 deaths per thousand. This positive trend continues, as displayed in Table 2, where the crude death rate decreased from 3.2 deaths per thousand in 2019 to approximately 3 deaths per thousand in mid-2023. This decline can be attributed to various factors such as the improvement in living standards, increased access to education, the expansion of healthcare services focusing on prevention and treatment, and better environmental conditions.

Table 2 Fertility rate for Saudi Arabia 2020–2023

Year	births per woman	Death/1000 people
1952	7.2	23.6
1962	7.2	19.7
1972	7.3	13.9
1982	7.1	7.4
1992	5.7	4.4
2002	3.8	3.7
2012	2.8	3.4
2019	2.2	3.2
2020	2.3	3.1
2021	2.2	3.2
2022	2.2	3.0
2023	2.2	3.0

Source World bank Macro trends, Saudi Arabia 2023

2.5 *Population Age Distribution*

The youth component dominates the age distribution of the population, with 0.167 million in 1980. The number increased to 8.6 million in mid-2020 compared to 8.4 in the mid of 2019 (General Authority for Statistics (2019a). Statistics indicate that the coming years will also witness more population entering the youth stage (between 15 and 34 years). According to the results of the General Authority for Statistics (2020a), in mid-2020, youth and children reached about 67% of the total population, with the youth increased by 0.26 million people from 2019, constituted about 37% of the Saudi population, compared to 11.6 million in the mid of 2019). The report also indicates that the total number of the population under 35 years until the middle of the year 2020 constituted about 47% of the total population, Table 3 indicates that the total number of the population under 40 years until the mid of the year 2019 reach about 24 million people and that above 60 years reach about 2%, representing about 69% and1.88% respectively., it also showed that the age groups between 40 and 59 years numbered 8.9 million people, representing 25.4% of the total population, as the number of this group increased from 8.7 million people in mid-2019 with a numerical increase of 0.23 million. The number of the age groups above 60 years overreached 1.922 million people, constituting only 5.5% of the total population of Saudi Arabia, although their number increased to reach 1.8 million in mid of 2019, with an increase of 40,042 thousand people.

Estimate of mid 2021 showed that Youth (15–34 years) constituted about 33% of the Saudi total population of 34 Million, with those above 35 years constitute about 43% of the total population (General Authority for Statistics 2021). The population summary report of Saudi Census 2022, showed that about 63% and of the population

Table 3 Population in Saudi Arabia by age groups in the first half of 2019

Age categories	Numbers (Million)
0–4	2.84
5–9	2.96
10–14	2.59
15–19	2.36
20–24	2.63
25–29	3.27
30–34	3.31
35–39	3.71
40–44	3.32
45–49	2.46
50–54	1.71
55–59	1.18
60–64	0.78
65–69	0.43
70–74	0.29
75–79	0.17
80+	0.20
Total	34.22

Source: General Authority for Statistics (2019a)

in Saudi Arabia is younger (less than 35 years old), while it represents 71% for Saudi population (General Authority for Statistics 2023b; Pinto 2023).

It is important to note that Saudi Arabia's Vision 2030 primarily seeks to address the needs of its young population in the future. This will be achieved through the implementation of plans and programs across all sectors, aiming to provide sufficient housing and essential infrastructure to meet the growing demand for services resulting from population growth. Additionally, there are expectations of high demand for various products and services. In the year 2017, the results of the population characteristics surveys 2017, indicate that the distribution of the population by sex in Saudi Arabia revealed that male represent 57.48 of the total population and 42.52% are females. These percentages are like the results of the 2016 demographic survey, where the percentage of males reached 57.44% and the percentage of females 42.56 (General Authority for Statistic 2020b).

2.6 Population and Standard of Living

The infant mortality index (children under one year) indicates a decrease in the rate of these deaths from 118 deaths per 1000 live births in the early nineties of the last century to about 17.4 deaths per 1000 live births per year in 2008. This significant decrease led to an increase in the number of years of life expectancy at birth from 53 years in the early nineties to about 73.7 years in 2009. As for the maternal mortality index which represented in maternal deaths due to causes related to pregnancy, childbirth and the postpartum, is decreased from 42 deaths per 100 thousand in 1989 to about 14.6 deaths per 100 thousand live births.

2.7 Population Issues and Challenges

The relatively high rate of population growth, which is associated with both the natural increase of citizens and the ongoing influx of immigrants, gives rise to several challenges that can be identified as follows: (General Authority of Statistics 2019b):

(a) Increasing spending on providing education, healthcare services, and housing to accommodate the growing population.
(b) The goal is to create job opportunities for the growing number of working-age citizens, particularly in the face of competition from foreign workers.
(c) It is important to sustain the ecological balance while taking into account the ongoing stresses on the environment due to population growth.
(d) Urban and industrial expansion. Addressing this situation requires continuing to develop the necessary policies to address these challenges and implement them in a way that ensures continuing to raise the standard of living of the population and achieving maximum benefit from the human resources resulting from population growth.

2.8 Residential Areas

Historically, the majority of the Saudi population has been either nomadic or semi-nomadic. However, this has changed since the discovery of oil between 1930 and 1939, leading to more stability. The country's economic activities are mainly concentrated in a wide area across the middle of the peninsula, spanning from Damam in the east, through Riyadh in the interior, to Makah-Medina in the west near the Red Sea. Saudi Arabia is notable for its expansive size, covering 2.15 million km^2, making it one of the least densely populated countries in the world. In 2020, the population density was recorded at 16.2 people per km^2. The urbanization rate has reached 2.17, the population is spread across 13 administrative regions within Saudi Arabia (Fanack Foundation 2020). As of 2019 estimates, five regions accounted for approximately 80% of the total population of Saudi Arabia, led by the Makah region (26.4%), followed by Riyadh (25.3%), then the Eastern Province (15.1%), Asir(6.7%), and Medina Urban and industrial expansion (6.5%). Addressing this situation requires continuing to develop the necessary policies. The swift growth of major cities in Saudi Arabia presents several challenges. These challenges include providing sufficient housing, managing congestion and traffic issues, tackling air pollution, addressing sanitation problems, and dealing with the rising cost of providing clean water for the population. Solving these problems necessitates the adoption of national spatial strategy policies and mechanisms. These approaches strive to achieve balanced and sustainable development both between and within the regions of Saudi Arabia (General Authority of Statistics 2019b).

2.9 Population Composition

During the past four decades, the development requirements in Saudi Arabia have led to a need for an increased number of expatriates in order to assist in the execution of development projects. As a result, they currently make up approximately 27% of the total population. With an anticipated growth in the proportion of the Saudi population, particularly the working-age segment, it has become essential to reevaluate the current demographics. This involves localizing jobs to create additional employment opportunities for the domestic workforce (General Authority of Statistics 2019b).

3 Problems and Difficulties of the Standard of Living and Quality of Life

3.1 Improving Health and Educational Conditions

To enhance the quality of life, it is necessary to persist in confronting challenges associated with the health and education conditions of citizens (Ministry of Economy and Planning 2009). To enhance health conditions, it has become essential to decrease the occurrence of contagious illnesses such as malaria and cholera. Additionally, lowering the prevalence of non-communicable diseases like hypertension, diabetes, and cardiovascular diseases is crucial. Furthermore, reducing the mortality rate of infants and young children, specifically those under the age of five, as well as maternal mortality, is also necessary. This requires expanding primary healthcare services, increasing efficiency in their operations, and ensuring access for all families throughout all regions of Saudi Arabia. It also entails providing general and specialized treatment at the second and third levels, and enhancing the effectiveness of healthcare services in their preventive, curative, and rehabilitative aspects while upholding quality standards. In addition to the general budget, diversifying the funding sources for health services to include cooperative health insurance revenues, endowments, gifts, and donations is essential. Regarding the educational situation, efforts must continue to eliminate illiteracy, expand preschool education (kindergarten), and ensure access to basic education for all individuals of educational age. Achieving qualitative improvements in education, along with quantitative expansion and qualitative development in higher education, are important goals. Furthermore, it is crucial to increase female participation in education and expand the range of educational specializations available for girls according to the demands of the labor market and society (Ministry of Economy and Planning 2009).

3.2 Housing

The housing industry is extremely important in modern societies, both socially and economically. There are many issues and challenges that accompany this sector, such as ensuring an adequate supply of housing, promoting home ownership among citizens, setting reasonable prices and wages for housing, and ensuring there is enough funding for housing and residential areas. Despite the efforts made by various parties involved in the housing industry, progress in this area is still not as ambitious as it could be. To address this, it is necessary to improve cooperation between different stakeholders, prioritize the development of housing for low-income groups, support the Public Housing Authority, and enable it to fulfill its mission. Additionally, it is important to complete the national housing strategy, create sub-strategies that consider population and living standards for different regions, and update them regularly. Based on population censuses and demographic surveys, addressing the issue of random housing in major cities should also be a priority and expedited (Ministry of Economy and Planning 2000).

3.3 Environmental Situation

The environmental situation in Saudi Arabia is facing several challenges due to population growth, urban and industrial expansion, increased transportation on land, air, and sea, as well as a rise in all types of waste. The pollution rates have increased, leading to a decline in the environmental index and negatively impacting the overall quality of life for the population. Consequently, addressing environmental safety and cleanliness has become a crucial issue. The Ninth Plan emphasizes the importance of considering the environmental aspect in the development policies and directions for the upcoming years. It also highlights the significance of strengthening the public environmental system, taking into account the environmental conditions amidst the projected population growth and expected development expansion. Additionally, institutional capacities for environmental work and the proper disposal of waste are supported. The plan prioritizes environmentally friendly projects across various sectors of development. As a result, there is an expected significant increase in efforts to preserve the environment during the Ninth Development Plan, driven by the awareness of the importance of this dimension and the commitment to achieving sustainable and environmentally friendly development (Ministry of Economy and Planning 2009).

4 Target Paths

4.1 Population Policy Path

This path represents one of the most important ways to achieve comprehensive development, especially considering the procedures and policies outlined in the population policy. These policies aim to accomplish specific demographic goals within the general framework of the population strategy for the countries of the Gulf Cooperation Council states. Additionally, these efforts should integrate with the relevant national strategies and align with the Millennium Development Goals (MDGs) established by the United Nations in 2000. The MDGs have the objective of eradicating poverty, ensuring universal access to primary education, promoting gender equality in education, reducing maternal mortality, decreasing the mortality rate of children under five years old, and addressing diseases such as HIV/AIDS and malaria. Furthermore, the MDGs emphasize environmental conservation and the development of a global partnership for sustainable development. This path aims to address all aspects of the population issue, such as the age and geographical distribution of the population, and to improve the health, educational, housing, and environmental characteristics of citizens because the citizen is the tool and goal of development. Accordingly, the population policy, which has begun to be prepared, is based on seven main pillars as explained by the Ministry of Economy and Planning (2009) including:

a. Population and Development: This pillar addresses issues related to rapid population growth, its distribution across different areas, age demographics, birth rates, and mortality rates among different population groups. It also involves studying how economic, social, and behavioral factors affect the population, as well as strategies for balancing population growth and available resources.
b. Health services and the health status of the population: This pillar focuses on several issues, including reducing death rates across different age groups, combating contagious and endemic diseases, diminishing disparities in healthcare access between regions in Saudi Arabia, and improving the quality of healthcare and social services provided, particularly for elderly citizens.
c. Education, training, and future challenges: One of the most critical pillars of human development and poverty alleviation, this pillar tackles various issues. These include eradicating illiteracy, addressing the educational needs of a growing number of children, expanding access to education and training facilities, and aligning educational outcomes with the labor market's requirements.
d. Women and Sustainable Development: This cornerstone covers several important matters, starting with eliminating illiteracy among women. It also aims to encourage female students to pursue scientific disciplines to balance the dominance of literary disciplines. Moreover, it focuses on eliminating obstacles that restrict women's participation in economic activities.

e. Youth (educational, health, and employment conditions): This pillar is crucial for population policy, considering that the youth can play an essential role in achieving developmental goals if their potential is effectively utilized. Therefore, it encompasses studying and addressing the needs of young people, promoting their engagement in sports, youth activities, and cultural facilities. It also includes efforts to update educational curricula to keep pace with scientific advancements and labor market demands, while also improving their health conditions and creating more employment opportunities to reduce youth unemployment.
f. Emerging issues: This pillar primarily concentrates on four major concerns: unemployment, poverty, environmental challenges, and housing issues. Each of these issues is examined to understand their nature, causes, and negative impacts on the population. Policies are then developed to mitigate these conditions and reduce their adverse effects.
g. Creating an enabling environment for implementing the population policy: This pillar involves three main elements: establishing population databases, developing training systems and programs within government bodies related to population, and conducting extensive research and studies on population-related matters. These efforts aim to provide the necessary information and expertise to effectively implement population policies.

4.2 The Path of the Standard of Living and Quality of Life

The standard of living and quality of life are closely connected to several indicators of development, including investment and employment rates, economic growth, and level of economic diversification. Additionally, the availability and quality of health care, education and training services, as well as basic amenities like water, electricity, sanitation, transportation, communication, and housing, all play a significant role. With regards to these factors, Saudi Arabia has embraced a comprehensive strategic planning approach to define the parameters of its future vision. The Eighth Development Plan was the initial phase of this vision, which brought about numerous economic and social advancements in the country. In line with this, the Ninth Development Plan aims to continue achieving diverse goals that will contribute to improving the standard of living and quality of life for its citizens (Ministry of Economy and Planning 2009).

4.3 The National Social Development Strategy Track

The Ministry of Social Affairs adopted a national strategy for social development that was very comprehensive. This strategy had a clear focus on the issue of poverty and the methods for addressing it. The main objective of this strategy was to promote social development. Poverty rates, both in terms of material and non-material aspects, would be reduced by improving the standard of living of those who are poor. This would be achieved by increasing their incomes, providing them with essential services, raising their levels of education and health, developing their skills and abilities, and empowering them economically so that they can actively contribute to the overall development process. It is important to note that the strategy not only aimed to address poverty but also focused on maintaining the living standards of all citizens, especially those in the middle-income bracket. The strategy aimed to prevent them from falling into poverty. The Ministry of Economy and Planning, in collaboration with the strategy work team, played a significant role in the preparation of the strategy. They developed a scientific framework that considered the specific conditions and capabilities of Saudi Arabia, as well as the global factors that influenced the country, such as high import prices, the global financial crisis, and global economic stagnation (Ministry of Economy and Planning 2009).

The Ministry of Social Affairs has adopted a comprehensive national strategy for social development. This strategy specifically focuses on addressing the issue of poverty and includes various mechanisms to tackle poverty. The ultimate goal of this strategy is to achieve social development. In order to reduce poverty rates, both material and non-material, the strategy aims to enhance the living conditions of the poor. This includes increasing their income, providing basic services, improving their education and healthcare, developing their skills and abilities, and enabling them to contribute to the development process economically. It is worth noting that the strategy does not solely focus on poverty, but also ensures the preservation of the living standards for other citizens, particularly those with middle incomes, and aims to prevent them from becoming trapped in poverty. The Ministry of Economy and Planning, in collaboration with a strategic team overseen by the Minister of Social Affairs, contributed to the development of this strategy by creating a scientific framework that takes into account Saudi Arabia's conditions and capabilities, as well as international factors such as high import prices, the global financial crisis, and the global economic recession. The implementation of the national strategy for social development involves the creation of a database based on specialized surveys. This database helps measure the level of poverty, identify the indicators of poverty, and determine the specific social groups and geographical areas where the poor reside. Additionally, the causes of poverty are studied in order to create and implement effective programs and policies to address poverty and minimize its negative effects. The strategy also encompasses various other aspects aimed at enhancing the overall quality of life and living standards, especially for those living in poverty. To achieve this, a general and direct targeting mechanism was adopted, and more focus was placed on the geographical dimension of the phenomenon of poverty. By setting clear mechanisms for geographical targeting to increase the effectiveness of programs and policies to cover the phenomenon of poverty hotspots. Whether at the level of the economy as a whole or at the regional level. Follow-up and evaluation mechanisms have also been developed to monitor the level of achievement and weaknesses in all regions of the Saudi Arabia; and identify the additional programs required by each region, to achieve the goals of balanced development and improve the quality of life in the various regions of the Saudi Arabia.

The national strategy for social development has the following objectives (Ministry of Economy and Planning 2009):

a. To provide opportunities for the poor to improve their physical and human assets by offering jobs, credit, education and training opportunities, health services, and improving their access to markets to sell their products.
b. To enhance the ability of the poor to participate effectively in various economic activities.
c. To improve the living standards of the poor by reducing their exposure to risks such as ill health, economic shocks caused by market fluctuations and natural disasters, and providing assistance in times of disasters and shocks.

The strategy also proposes policies to address poverty across five dimensions:

First: Promote balanced economic growth by implementing policies that accelerate economic growth and distribute its benefits evenly among different regions of Saudi Arabia and various social groups. Second: Empowering the poor through policies that enable families and individuals from disadvantaged backgrounds to own production tools that increase their income. This also includes increasing the productive capacities of families engaged in productive activities and small and medium enterprises, as well as policies to improve employment opportunities and wages.
Third: Developing human capital and building capacity. This dimension includes policies aimed at improving health, education, training, municipal services, housing, and other related areas.
Fourth: Implementing a social safety net which includes policies to activate social security measures and strengthen the efforts of Saudi charities and voluntary organizations in addressing poverty.
Fifth: Rehabilitating the institutional structure and promoting good management practices. This dimension involves implementing policies and programs to enhance the performance of relevant agencies responsible for implementing the strategy.

5 Development Strategy and Future Vision

Achieving a balance between economic growth, natural resources, and population growth rates, while maximizing the current and future age structure of the population and upgrading various development indicators, will result in an improvement in the living standards and quality of life for citizens.

5.1 Goals of the Development Strategy

The general objectives of the development strategy can be summarized as follows:

a. Improving the living standards and lifestyles of the citizens.
b. Striving to achieve a balance between population growth and the availability of natural resources.
c. Rationalizing immigration to cultural centers in different regions of Saudi Arabia.
d. Decreasing the percentage of expatriates in Saudi Arabia's population. e. Reducing the mortality rates of infants, children under the age of 5, and mothers.
e. Increasing opportunities for the utilization of human resources, particularly capable and competent young individuals.

The specific objectives of the development strategy include: Reducing the annual growth rate of expatriates to approximately 1.9% on average each year; eliminating extreme poverty and achieving economic empowerment for disadvantaged families; ensuring an adequate number of employment opportunities for members of needy families; and, encouraging a growing proportion of needy families to become productive and enabling as many families in need as possible to own their own small businesses (Ministry of Economy and Planning 2009).

5.2 The Policies of the Development Strategy

The development strategy aims to increase awareness of population issues and their relationship to development issues through various forms of media, such as visual, audio, and print. It directs economic and urban development efforts towards medium and small cities by increasing government spending and private investment, both national and foreign, in these areas that are less developed. In addition, it focuses on developing the administrative and organizational capabilities and infrastructure of these cities and establishing new residents' centers. These centers are seen as drivers of growth that will enhance competitiveness at the regional and international levels. The new economic city projects serve as examples of these centers, utilizing the potential of the young population to drive development and meet the requirements of the public and private sectors. Support funds are provided, along with the expansion of financial institutions and their programs, especially those related to employment training for small and medium enterprises that heavily rely on national labor, particularly in less developed regions. Measures are taken to reduce the rates of genetic and other diseases by ensuring that medical examinations are conducted before marriage. The program also expands to monitor and treat genetic diseases among newborns, providing health care services to premature and underweight children, and continuing immunization programs against communicable diseases. The encouragement of safe childbearing behavior and the expansion of motherhood and child services are promoted through health education, awareness programs promoting birth spacing, longer breastfeeding periods, avoidance of early or late pregnancies, attention to the nutritional status of young mothers, combating anemia among pregnant women, expanding medical care services for pregnant women and obstetric services, and encouraging postpartum follow-up. Efforts are made to improve the quality of public education, health care services, and social services. Furthermore, there is a focus on achieving greater integration between government and private initiatives, particularly in the provision of job opportunities and stable employment, to improve the standard of living for the population. (Ministry of Economy and Planning 2009).

6 The Concept of Food Security

Opinions varied on the concept of security, its components, and methods of achieving it, and accordingly its definitions varied, as each definition focused on different aspects and details, and with the increasing problems affecting human safety and the stability of society, appeared the concept of comprehensive security and its accompanying use of specialized security terms such as food security, Environmental security, water security, cultural security, social security, and economic security (Al-Zahrani and Moneer 2007).

The concept of food security, according to the definition by the Food and Agriculture Organization (FAO 1996) is "providing food for all members of society in the quantity and quality necessary to meet their needs on an ongoing basis for a healthy and active life."This is different from the traditional concept of food security, which is related to achieving self-sufficiency by based on the state's resources and its local food production capabilities. Hence the importance of natural, human and financial resources to be exploited as determinants of food security (Al-Zahrani and Moneer 2007). Therefore, societies are divided into:

a. Societies that have natural, agricultural human and financial resources. This type of community enjoys sustainable food security. As most of its food needs are produced locally, it does not have any threat to food security.
b. Societies that do not have enough natural agricultural resources for local production but have financial resources that enable them to import their food needs from the countries of the outside world. This type of society also food secured as long as they live in a cooperative and sound regional and international environment.
c. Communities that possess agricultural natural resources, but do not possess the economic resources necessary to exploit them, these are societies that lack food security in the short and perhaps medium-term, and their food security can be achieved once the financial resources necessary to exploit agricultural resources are available.
d. Societies that do not have any natural agricultural resources and do not have the financial ability to import sufficient quantities of food from abroad, this is the type of societies that suffer from the problem of food security, whether in the short or long term.

At the present time, the importance of food security is increasing, as it is considered as one of the most important elements of national security. Most of the major power almost monopolize a large proportion of the surplus agricultural and food production and can use it as a weapon to serve their purposes. Hence, food insecurity is considered one of the most important external threats to the security and sovereignty of societies. In addition, it is one of the strongest causes of the spread of crime and the emergence of negative social and economic diseases in society, which negatively affects social security and makes society repel investors and producers (Economic and Social Commission for Western Asia 2020).

There are several indicators and criteria to determine the level of food security in society (Al-Zahrani and Moneer 2007), the most important of which are:

The percentage of self-sufficiency in strategic commodities (with the prevailing consumer food pattern in the community)

a. The ratio of the value of agricultural production to the imported agricultural products
b. The ratio of agricultural imports to total imports.
c. The ratio of spending on food to the total national income.
d. Annual fluctuations in agricultural production.
e. The contribution of agricultural production to the gross domestic product.
f. Average per capita share of the value of agricultural production.
g. Ratio of net agricultural imports to gross national product.
h. Ratio of food stock to annual consumption.

7 Current and Prospects for Food Security in the Arab World

The issue of food security is considered one of the most important issues that grab the world's attention from the main challenges in the Arab world (Ministry of Environment, Water and Agriculture 2018). Despite the availability of natural and human resources, Arab agriculture did not achieve the targeted increase in production to meet the demand for food, thus, the gap widened. Hence, most of the Arab countries import more than half of their basic food commodities, which makes them highly vulnerable to the fluctuations of global markets, as well as the continuous increase in population growth is not accompanied by an increase in agricultural and food production. Arab countries have increased their interest in providing the food commodities following the global food crisis, that reached its severity in 2008, which was represented by an increase in the prices of major food commodities and a decrease in the quantities of imports. Moreover, climate changes were the main cause of natural disasters and resulted in a lack of food commodities. Accordingly, Arab countries need to take many exceptional measures, including subsidizing food prices, reducing exports of food commodities, abolishing import taxes, and increasing the wages of workers in the agricultural sector. To achieve food security, the efforts of the countries of the world as a whole must be combined to face any challenges and obstacles that prevent its access, as well as to develop various solutions to ensure the continuity of food supplies in the world (United Nations Publications issued by ESCWA 2020; Abunasser et al. 2022).

8 Current and Prospects for Food Security in the Saudi Arabia

Saudi Arabia attaches great importance to achieving food security, especially in light of the challenges it faces in this field. The Ministry of Environment, Water and agriculture (2018) summarized the most important challenges as follows:

a. Lack of clarity about the governance system for food security.
b. The amount of natural resources available.
c. High rates of food waste
d. Lack of a complete agricultural market information system, especially on food quantities
e. The need to spread a culture of nutritional education.
f. The risks that result from climatic changes that causes many natural disasters, such as storms and floods.
g. The need for highly qualified national cadres in the field of food security.
h. Heavy dependence on imported food supplies
i. Geographical and commodity concentration of foodstuffs in limited countries.
j. The instability in the region during the last decade.
k. The high costs of agricultural production and the strategic food reserve.
l. Challenges facing agricultural investment abroad and at home.
m. The spread of unhealthy eating habits.

The guidelines for the food security strategy (Ministry of Environment, Water and Agriculture 2018) in the Saudi Arabia focus on the effective participation of the qualified private sector, close coordination between the concerned authorities and risk management in proportion to the type of risk. In addition to developing an integrated approach to food security that includes formulating a new vision for food security that allows meeting the needs of strategic food commodities, both in the case of stability and emergency.

A new vision of food security has been formulated that allows meeting the needs of food commodities in a stable and emergency situation that is represented by:

According to (Ministry of Environment, Water and Agriculture 2018) the strategic objectives to achieve the Saudi Arabia's vision for food security summarized as follows (Fig. 1):

In order to achieve these five strategic goals, several executive programs were translated, entrusted with their implementation by the most prominent ministries and bodies concerned with food security in the Saudi Arabia headed by the Ministry of Environment, Water and Agriculture. These programs include:

1. achieve a sustainable local food production system for commodities with a preferential advantage as follows:
   a. Raising the levels of self-sufficiency in goods suitable for the Saudi environment.
   b. Encouraging reliance on sustainable practices in local production.

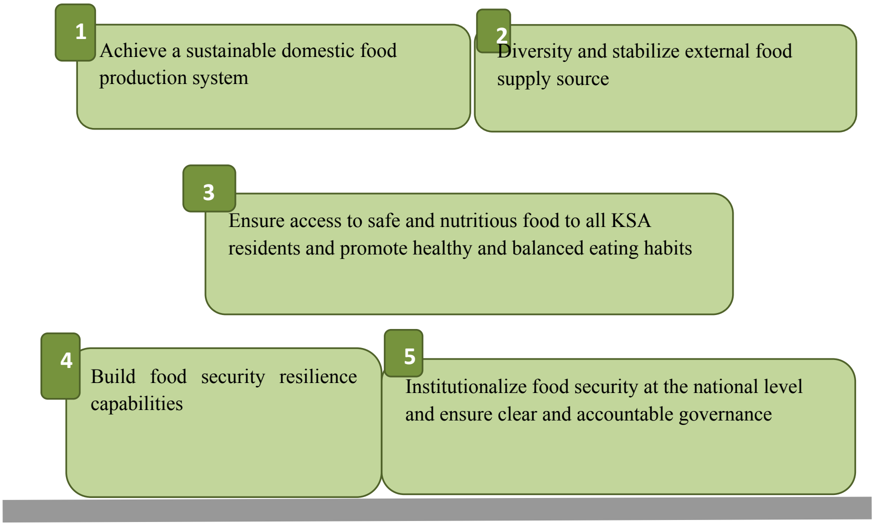

Fig. 1 Strategic objectives of the Saudi Arabia's vision for food security

c. Supporting small farmers and developing agriculture in rural areas.
d. Supporting the local development of food industries as it is the most important strategic agricultural products.
e. Preparing programs to reduce food loss and waste.

2. Achieving diversity and stability of external food sources:

a. Transforming the Saudi Arabia into a regional center for food trade.
b. Activating the mechanisms of cooperation in the field of food security among the countries of the Gulf Cooperation Council.
c. Enhancing the Saudi Arabia's participation in international organizations and agreements on food security.
d. Preparing and launching a plan for agricultural investment abroad focusing on food security.

3. Ensuring access to safe and nutritious food in the Saudi Arabia and encouraging healthy, balanced eating habits:

a. Launching awareness programs to encourage healthy eating habits.
b. Adopting integrated programs concerned with the neediest groups (social safety).
c. Ensuring the implementation of modern systems and procedures for food security in a manner that rises to international standards.

4. Building ready capacities to face risks related to food security:

a. Designing an effective information and risk management system in the field of food security.

b. Develop protocols and apply systems to manage crises and emergencies.
c. Develop appropriate policies for managing strategic stocks in partnership with the private sector.

5. Developing an institutional work model at the national level and ensuring clear and responsible governance:

   a. Formulating an effective governance system responsible for setting the regulatory framework for food security in the Saudi Arabia.
   b. Preparing awareness and training programs to build national capacities and raise their efficiency.
   c. Encouraging investment in infrastructure necessary for food security.

9 Food Security and Population Growth in Saudi Arabia

Population increase linked to food security. The scarcity of resources and the existence gap between available food and the growing needs of the population for food threatens food security, so it is necessary to determine the growth rates for each of them.

Molotoks et al. (2020) studied the future global impacts of climate change, population, and land use change on food security to 2050 and they found that population growth and land use change could have the largest impact on food security rather than climate change. On the other hand, Maisonet-Guzman (2011) reveal a positive association between agriculture production and population growth, opposing to the neo-Malthusian model, assuming negative relationship between population growth and agriculture production. The significant effect of population growth on agriculture output was also substantiated by study by Aiyedogbon et al. (2022) in Nigeria and Yimer (2006) in Tehuledere woreda, northern Ethiopia. In the same line Hall et al. (2017) indicated that anticipated speedy population growth will be the main factor of food insecurity and widespread undernourishment in Africa.

The Saudi Arabia's total food imports during 2019 amounted to about 81,369 thousand tons, with an increase of 1.4% over the year 2018, which amounted to about 80,248 thousand tons. During the year 2019, the Saudi Arabia's food imports achieved an annual growth rate equal to 7.58%, with an estimated increase of the imported amount of food by about 47,202.42 thousand tons over the period average of 1993–2019. While the population of Saudi Arabia during 2019 was about 34.21 million people, with an increase of about 2.3% over the previous year 2018, where the population size reached 33.41 million people. With an annual growth rate reached about 2.59% during the period (1993–2019).

This means that the imported amount of foodstuffs increases at a large rate to meet the increase in the population growth rates in the Saudi Arabia, i.e. an increase of 1% in the population requires an increase in the Saudi Arabia's food imports by about 3.3% during the period of 1993–2019 as shown in Fig. 2.

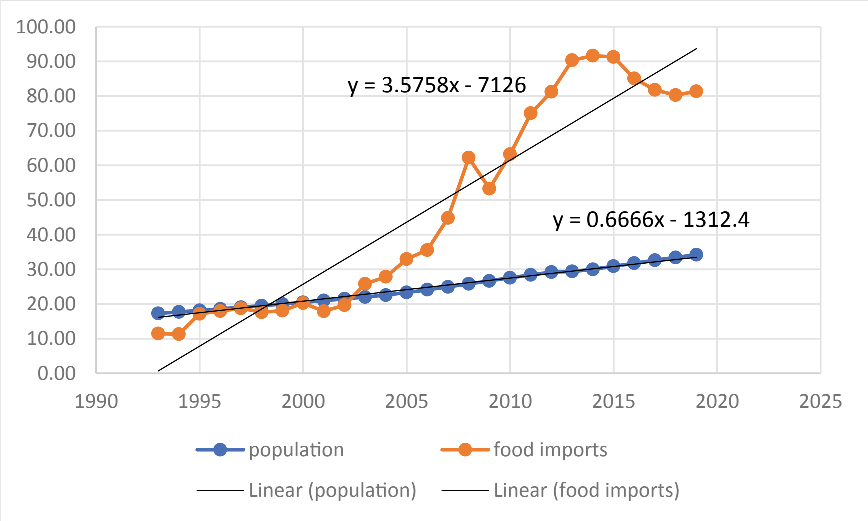

Fig. 2 Value of food imports and the number of population in the Saudi Arabia during the period 1993–2019. *Source* Prepared by the authors based on data from 1993 to 2019

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Chapter 17
Strategic Food Reserve Management and Food Security in Saudi Arabia

Mutasim Mekki Elrasheed

Abstract Strategic food reserve is a strategy that is implemented by many countries in the world, including Saudi Arabia (KSA), to sustain food security and encounter international food market shocks. In this context, the Ministry of Environment, Water and Agriculture (MEWA), KSA, has assigned the role of the supervision and execution of food security, including strategic food reserve, to the Saudi Grain Authority (SAGO) (Currently known as General Food Security Authority). This chapter describes the strategic reserve and its management as a tool for sustaining food security in KSA. It also sheds light on the role of SAGO in managing strategic food reserves and achieving food security. Moreover, it describes the locations and capacities of storage facilities; grain buying modalities; grain selling and distribution practices; and flour mill companies in KSA. It is clear that private business has fully engaged in achieving KSA Vision 2030 of flour mill sector privatization. It is also evidence that grain storage capacity is increasing over time and is distributed all over the country. Furthermore, KSA has a well-established body called the commodity abundance committee (CAC), constituted of representatives from different institutions, including SAGO, responsible for monitoring food strategic reserves in the Kingdom. In doing so, the CAC used active early warning systems to identify food stock levels in the country and determine the required actions accordingly. Actions range from the provision of finance, support, and/or direct purchase of critical food items. It is also evidence that SAGO has succeeded in sustaining a stable food reserve during critical times.

Keywords Commodity Abundance Committee · Fodder · Food security · Food stockpiles · General Food Security Authority · Saudi Grains Organization (SAGO) · Strategic food reserve · Wheat

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1 Introduction

A strategic reserve is the reserve of a commodity that is controlled and maintained by the government to protect the economic and national security of a country or to meet unforeseen events. The term strategic reserve is an emerging term on the global scene. Yet, the stoking process has been known since ancient times, especially in the field of foodstuff and in expectation of emergencies. In this regard, it is important to differentiate between different types of stocks. According to Teng and Darvin (2018), in their quotation of Abbott (2013), there are two types of stocks: working stocks and buffer or reserves stocks. Working stocks or pipeline stocks are the stocks that are held by agents/organizations to ensure continuous operations. On the other hand, reserved stocks are the food that is stored more than the working stocks. Both types of stocks are usually used to influence markets or maintain food supplies over the years.

According to Caballero-Anthony et al. (2015), reserves are classified into three categories of stockpiles: public, private, and household. The first category is directly owned, monitored, and administered by the government, while the second category is owned by private enterprises but jointly monitored and co-administered by private owners and the government. On the other hand, household stockpiles are the stock that is directly owned by the consumer and/or small producer and monitored by the government. They went further and classified public stockpiles into four types: emergency/humanitarian stocks, buffer stocks, safety net stocks, and stocks for trade. The emergency/humanitarian stocks are stocks that deal with food access and are used to protect vulnerable groups in the event of food shortage during emergencies, while the buffer stocks are used to guarantee stability in the availability and price of food. Moreover, safety net stocks are directed to improve the availability and access for certain groups of the population who face chronic food security and the fourth category, stocks for trade, is usually held by exporting countries.

Based on the fact that the Kingdom of Saudi Arabia (KSA), is a water-stressed country and heavily depends on food imports for sustaining its food security (Baig et al. 2019), the Ministry of Environment, Water and Agriculture (MEWA) has developed a comprehensive national food security strategy. The supervision and execution of this strategy is assigned to the Saudi Grains Organization (SAGO) according to MEWA Minister's decision No. 1/620, dated 1st July 2017 (17/10/1439 H) (SAGO 2021). Moreover, MEWA has identified a 10-priority scope of work, among which the food strategic reserve program occupied the second position. However, the high costs associated with food strategic reserve and storage are considered among the challenges that face the achievement of food security in KSA (SAGO 2021). It is worth noting that, MEWA has adopted the initiative for an effective food strategic reserve and storage program, which includes an early warning system and agricultural markets information, in its national transitional programs to encounter food security risks (MEWA 2022).

The objective of this chapter is to describe strategic reserve management in KSA as a tool for sustaining food security. This chapter is divided into five sections.

Section 1, is the introduction, while Sect. 2, gives a snapshot of KSA agro-food products; Sect. 3, covers the basic concepts of food security and strategic reserve. Section 4 is devoted to strategic reserve management in KSA, while the last section is the drawn conclusion and prospect.

2 Snapshots on Saudi Agro-Food Products

The Kingdom of Saudi Arabia (KSA), the largest country in the Arab and Middle East country and the main petroleum producer in the world, is located in the south-western part of Asia. The country is well endowed with different natural resources and diversified environmental conditions. However, the environmental situation in the country is not suitable for producing sufficient food products to meet its population needs and reach the level of domestic self-satisfaction. The weather condition of KSA is hot, arid, and dry; the soil is sandy with low fertility; and the water sources are very limited to meet agricultural needs. Moreover, a very minute percentage of land (1.6%) is classified as arable land (World Bank 2022). Such a situation pushed the Kingdom to spend more than 7 billion USD in 2019 on importing its food requirements (WITS 2022). Statista (2021) estimated the average self-sufficiency ratio of food items in KSA in 2019 as 36.1%. However, despite the unsuitable conditions, the agricultural sector contributes significantly to the KSA economy. Available literature showed that the agricultural sector contributes substantially to achieving food security and attaining self-sufficiency in the country. In this regard, it is worth mentioning that, in 2021 KSA has achieved the self-sufficiency level from fresh milk (121%), table egg (112%), and date (118%) and is moving forwards to attain it from other agricultural commodities (General Authority for Statistics 2021). Moreover, about 300 thousand small-scale producers are engaged in the agri-business and about one million of the population earn their living from agriculture. The sector also adds 64 billion Saudi Riyals to the country's GDP and supplements the non-petroleum GDP by 4% (MEWA 2017).

The kingdom has gone steps ahead in sustaining its food security. No wonder, Vision 2030 emphasized reducing the dependence on the oil sector, diversifying the country's income sources, sustaining food security, and attaining efficient use of water in addition to others (Vision 2030 2023). In this context, MEWA (2017) has released its national agricultural strategy for 2030. The strategy gives much attention to agro-food products: agricultural products (cereals, vegetables, fruits, and green fodders), livestock and poultry products (live animals, red meat, broiler chicken, fresh milk, and table egg), and fishery (both captured and cultured fish). The strategy has seven strategic objectives and five pillars. Moreover, in 2020 KSA declared a significant improvement in the self-sufficiency level of certain agro-food products. For instance, the Kingdom has achieved self-sufficiency from dates, table eggs, and fresh milk (MEWA 2020a). However, it achieved 60% and 41% sufficiency levels from broiler chicken and red meat, respectively (MEWA 2020a, b). Baig et al. (2022)

argued that strengthening the agriculture extension systems in KSA would help in achieving food security and addressing the adverse climate change effect.

In recent years, Saudis food imports witnessed a continuous increase over time, predominantly cereals, rice, meat, and dairy products. In 2019, food imports grew by 6.5% compared with 2018 and reached 144.3 billion US dollars (Best Food Importers 2021). According to Baig et al (2019), the main imported food items were barley, sheep, rice, chicken, and wheat constituting about 40% of the total imports. In this regard, Best Food Importers (2021) argued that KSA is the major importer of cereals, with a value reaching up to 4.3 Billion US dollars. However, rice, barley, corn, and wheat are the main imported cereal crops. In this context, Kashifi et al. (2022) stated that the import of major cereal crops by Saudi Arabia significantly reduces the country's water footprint (embedded water in the trading of commodities), that is, solves the problem of local water shortage. They also argued that the annual decline of consumable water footprint due to the imports of wheat, maize, rice, and barley is estimated at 24 billion cubic meters (M^3) per year on a global scale. Moreover, trades of cereal crops in the Kingdom significantly reduced water consumption, energy usage, and CO_2 emissions.

3 Concept of Food Security and Strategic Reserve

3.1 Concept of Food Security

Food security is the situation that "exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active productive and healthy life" (FAO 1996). According to FAO (2001), the objective of domestic food security is the assurance of readily available food supplies in sufficient quantities and quality within the purchasing power of even the poorest consumers all year round – a target that centered heavily on the improvement of production, processing, storage, and distribution. Based on the aforementioned information, food security is composed of four dimensions: availability, accessibility, utilization, and sustainability. Food availability is the situation that occurs when sufficient quantity and quality of food exist in a particular place and time (Brown et al. 2015; Ahmed et al. 2022). Based on the available literature, food availability is concerned with the supply side of food security (Brown et al. 2015), and is composed of different items such as food production, trade system, packaging transport, and storage (Ingram 2011). Whereas, the focus of food accessibility is the demand side of food security which is greatly affected by the physical, economic, social, and technological situations of the individuals. Food utilization refers to the efficient utilization of the available and accessed food to meet an individual's nutritional needs. Many factors in the literature are found to be affecting food utilization such as food safety, quality, consumption patterns and trends, food processing, storage, and preservation facilities. Lastly, food stability refers to the sustainability of all food security dimensions over time (Ahmed et al. 2023). In all aspects, household access to a stable and sustainable food supply is a prerequisite for the formation of food security.

3.2 The Concept of Strategic Reserve

Strategic grain reserves, which are also called emergency food reserves or food security reserves, have gained great attention after the global food crisis of 2007–08 (IFPRI 2010). Since then it is considered a crucial element of food security strategy in the world. It is worth noting that the strategy of food reserve has been in use for thousands of years and proved to be highly effective in sustaining food, nevertheless, they need to be properly established (Murphy 2009). Nowadays, grain reserves are gaining increasing attention for protecting food supplies from price and supply uncertainty. Moreover, most governments maintain a belief that food reserves can act as a buffer from disasters and climate change shock, moderate interruptions in trade due to export bans (Lassa et al. 2019), and smooth out price volatility (Murphy 2009). Furthermore, Ahmed et al. (2012) described the working mechanism of the strategic reserve agency in Sudan, which can be summarized as purchasing and storing grains during the surplus seasons to protect producers from grain price drop and selling and/or distributing it during deficit seasons or in cases of emergencies. However, this mechanism might not suit all countries due to the particularity of each. The stabilization of commodity prices improves the welfare of both producers and consumers by developing the whole business. In this regard, Larson et al. (2014) developed a competitive storage and trade model, based on Middle East and North Africa (MENA) wheat markets and the rest of the world. They argued that the strategic inventory policy succeeded in protecting consumers in the region from steep price spikes in addition to lowering the price in the MENA region. However, they mentioned that achieving successful strategic reserve programs requires holding greater reserves. On the other hand, Pierre et al. (2018) studied the impact of the Tanzanian National Food Reserve Agency (NFRA) on maize market prices and argued that the pricing strategy used by NFRA had a limited overall impact on prices during the period 2010–2014, despite its significant impact on some regional markets.

The idea of food reserves comes in response to the timeless characteristics of agriculture production, that is, the existence of seasonal constant, inelastic demand coupled with variable short-run supply (Murphy 2009). Accordingly, government intervention through reserving food is to correct the aggregate food market's failure, smooth out spatial and time prices volatility, complement or replace the private sector and/or prepare for food emergencies (Murphy 2009). However, for developing countries, two cautions should be taken into consideration. The first one is the unavailability of the required food on the world market; and, the second is the unaffordability of food, especially during the prevalent food shortages.

The grain reserves strategy might not be a suitable measure for solving chronic hunger as people who live with hunger lack purchasing power, not a food supply (Murphy 2009). Accordingly, a grain reserve policy in a situation of chronic food insecurity should be complemented by other policies, containing some methods of food aid such as the U.S. food stamp program, consumer subsidies, or other kinds. From a policy perspective, grain reserves have some drawbacks: it costs money, creates distorted markets; includes guesswork based on transparent and accountable verdict, in contrast, competition is better financed, informed, and politically powerful (Murphy 2009). Along the same line, Würdemann et al. (2011) argued that, despite the numerous and valuable role played by food reserves on food security, but still maintaining and operating publicly held reserves has some disadvantages such as high cost which is usually incurred in the investment, maintenance, monitoring and operating reserve. In this regard, the World Bank (2021) identified three areas for improving strategic grain reserves to enhance the food security situation in Zambia and Zimbabwe. These areas are (a) reduction of the costs of strategic grain reserve management (fiscal costs); (b) improvements in the delivery and distribution of emergency assistance; and (c) increasing the role of the private sector.

Based on the experience of some South Sahara African countries, it was found that the usage of on-farm and off-farm storage capacity and agro-processing techniques add considerable value to products and increase their shelf life (Adeyeye 2016). Furthermore, the same author added that the shortages of food preservation capacity in the South Sahara African countries are considered among the main limiting factors that affect their food and nutrition security. Accordingly, he stressed the importance for those countries to promote and adopt the mentioned techniques to ensure staple food supply and attain national food security.

Food stockpiling was performed by many countries around the world. Some countries depend on national production, while others involve in government-to-government trade, importation, or even government-to-private trade (Teng and Darvin 2018). However, for some MENA countries, due to the reoccurring disruption of trade and adverse environmental conditions, they invested in strategic grain reserves, took measures for achieving self-sufficiency, and acquired foreign land for investment. Yet, the accumulation of food stocks is the most efficient for them (Wright and Cafiero 2011).

4 KSA Food Security and Strategic Reserve

The KSA Cabinet approved the comprehensive national food security strategy in 2018 (decree No. 439 dated the first of May 2018 (15/8/1439 AH)) (SAGO 2022a). According to SAGO (2022a), a new vision of food security was set taking into mind two situations: steady state and emergency state. The vision for the steady state is to ensure safe and nutritious food for all Saudis stably and sustainably and for an emergency, the state is "to quickly and reliably ensure affordable safe and vital commodities for all Saudi during times of crises". SAGO also identified the methodology for commodity selection in cases of steady and emergency states. For steady state, the methodology of selection is based on three steps: categorized food commodities by type of nutrient contribution in the human diet (based on WHO guidelines); screen out food commodities based on the lowest share of local production and imports; and fix appropriate quantities and promote a healthier diet, and adding value chain analysis. On the other hand, the methodology of an emergency is four: screen out commodities based on the lowest share of local production and imports; select a list of 6 commodities that ensure 2000 kcal/day and maintain a balanced diet; screen out commodities on non-affordability, non-suitability for dry storage and non-sustainability for production or handling; and add dependencies (select strategic food commodities).

Moreover, SAGO priorities and scope of work have been identified, which include ten-food security areas. These areas are baseline and analysis of the current situation of food security; food strategic reserve program; integrated governance models for coordination between sectors and stakeholders; food security early warning system (including agricultural market information system); food loss and waste production program; national policy for trade and import of food and partnership agreements with countries; regulatory analysis GSFMO and other intuitions to determine strength, weaknesses, and improvement; food security and nutrition training and awareness abroad, in addition to, promoting KSA participation in food security committee agreement and treaties (SAGO 2022a). Likewise, indicators for achieving food security in KSA such as affordability, availability, quality and safety, and resilience have been identified. Indicators of affordability are monthly price monitoring, tailored agricultural tariffs, a variety of social safety programs, and agricultural finance (SAGO 2022d), while for availability are: government focus on agricultural R & D, transportation network, irrigation infrastructure, and food loss & waste baseline. However, indicators for quality and safety are excellent public health; healthy lifestyle; food safety & food storage regulations and resilience are agricultural productions; effective weather-focused early warning system to mitigate risks; commitment to developing vegetation and combat desertification; and Saudi green initiatives as the roadmap for sustainable future (SAGO 2022d). Moreover, KSA has identified five strategic objectives for food security these are (SAGO 2022a):

- Achieve a sustainable domestic food production system for privileged commodities,
- Diversify and stabilize external food supply sources,
- Ensure access to safe and nutritious food for all KSA residents and promote healthy and balanced eating habits,
- Build food security resilience capabilities and
- Institutionalize food security at the national level and ensure clear and accountable governance.

4.1 Strategic Reserves in KSA: SAGO Establishments, Objectives, Vision, and Mission

The SAGO, which is formerly known as the General Organization for Silos and Flourmills (GSFMO), was established in 1972 by the Royal Decree Number (M/14) issued on 8th of May 1972 (25/3/1392 AH) and amended by Royal Decree Number (M/3) dated 26 October 1985 (12/2/1406 AH). Moreover, Saudi Cabinet Resolution Number (35) dated 9th November 2015 (27/1/1437 AH) was issued, which include approval for establishing four flour mills joint-stock companies, in addition to, approving the amendment of the name of the General Organization for Grain Silos and Flour Mills to "General Organization for Grains" and its reorganization (SAGO 2022a). Therefore, the Cabinet Resolution Number (328) dated 9th of May 2016 (2/8/1437 AH) was issued approving the organization of the Saudi Grain Organization, provided that the corporation undertakes the management, operation, and development of silos, in addition, to the tasks of organizing, monitoring and supervising the activity of flour mills with the following duties and responsibilities (SAGO 2022b):

- Setting up the activity of silos and flour mills to attract investors to intrude into this sector.
- Licensing the activity of silos and flour mills, and monitoring the performance and duties of the licensed firms.
- Setting quality and safety standards related to the activity of silos and flour mills in coordination with the relevant ministries and government agencies, and monitoring the implementation of those standards
- Buying and selling wheat, finding a reserve stock of wheat sufficient for the Kingdom's needs, and completing its balance periodically.
- Organizing, controlling, and supervising the activity of flour mills.
- Monitoring the quality of wheat and what milling companies produce from flour.
- Providing the necessary quantities of wheat required for full operation of the flour mill companies in accordance with the pricing policy proposed by the SAGO which regulate the activity of silos and mills for flour production, and in accordance with the government policies for market support.
- Monitoring the competition rules in the field of providing silos and flour mills activity services.
- Working to protect consumers from the activities related to silos and mills activity products.
- Proposing the pricing policy for the products from flour mill activity.
- Barley Import:
- The feed barley import file was assigned to the SAGO according to Royal Decree No. (40657) dated 27th of May 2016 (19/8/1437 AH). Starting from October 2016, SAGO was required to distribute and sell barley along with maintaining an appropriate strategic reserve for emergency circumstances.
- According to the Council of Ministers Resolution No. (197) dated 10th of November 2020 (24/3/1442AH), the private sector is responsible for the importing and selling of feed barley according to the regulations contained in the Resolution.

4.1.1 SAGO's Vision

According to SAGO (2022e), the vision of SAGO is written: "To lead the food security efforts and ensure the provision of the strategic goods at reasonable prices and the sustainability of the strategic and reserve stock of food goods and their reliability".

4.1.2 SAGO's Mission

The mission of SAGO is "To enhance the development of the sector of food goods related to the strategic stock by the efficient organization, reliable data and analysis of the market and effective response to emergency situations" (SAGO 2022e).

4.2 Strategic Reserves Facilities, Locations, and Capacities

KSA has 27 silos that are used for strategic grain reserves. These silos are distributed all over the kingdom. The numbers of silos in Riyadh are four, whereas in Qassim and Hail are three each; but for Jeddah, Dammam, Khamis Mushayt, Al-Jouf, and Wadi Al-Dawaser, are two each, and for Tabouk, Madina Monawara, Al-Kharj, Al-Jumom, Jazan, Al-Ihsaa, and Yanba is one each. The total grain storage capacity in KSA is 3.44 million tons (SAGO 2022a, b, c, d, e) with Riyadh, Jeddah, Dammam, Qassim, Khamis Mushayt, Tabouk, Madina Monawara, Hail, Al-Jouf, Al-Kharj, Wadi Al-Dawaser, Al-Jumom, Jazan, Al-Ihsaa, and Yanba storing capacity of 535, 260, 220, 485,120,100,60, 300, 100, 210, 500, 250, 120, 60, and 120 thousand metric tons, respectively (SAGO 2022b).

The SAGO also owns considerable unloading capacities for imported wheat amounting to 10 - 12 thousand tons per day in Jeddah Islamic Port, King Abd Al-Aziz Port in Dammam, Jizan Port, and Yanbu Commercial Port (SAGO 2022a).

4.3 SAGO and Food Security in KSA

With the onset of the Corona pandemic and in the context of unifying and coordinating efforts and sustaining food security in KSA, a committee for monitoring food commodities abundance was established. Members of this committee are MEWA; Ministry of Commerce and Saudi General Authority of Foreign Trade; Ministry of Municipal & Rural Affairs & Housing; SAGO, Saudi Food and Drug Authority (SFDA), and Zakat, Tax and Customs Authority (ZTCA). In 2019, a team of representatives from 10 different identities emerged from the commodity abundance committee to monitor the levels of strategic reserve and the stability of food commodities supplies. These identities are Ministry of Commerce; Risk Unit at

Royal Court; Saudi General Authority of Foreign Trade; Council of Saudi Chambers; General Authority for Statistics; Saudi Agricultural and Livestock Investment Company (SALIC); Ministry of Municipals & Rural Affairs & Housing; SAGO, SFDA; ZTCA and Agricultural Development Fund. The main tasks of the team are to (SAGO 2022a):

- Perform daily monitoring of strategic stock levels of grains (wheat, barley, and flour); local meat production (fish, red meat, and local broiler chicken); table eggs and fresh milk; catering goods; import risks and external food conditions and its alternatives.
- Draft, suggest, and revise proposed actions to legalize and redirect necessary food stocks, legalize export, and use possible scenarios.
- Review and identify calorie intake per person from different food groups according to WHO.

4.3.1 Mechanism for Determining the Abundance Index of Basic Food Commodities in the Kingdom

The monitoring team of the Commodity Abundance Committee (CACO) approved scientific methodology to update a daily monitoring report on the level of stocks and supplies of 19 basic food commodities. The team used a scale composed of three levels (safe supply level, Medium supply level, and supply level required government intervention) to describe the status of the commodity supply level in the kingdom. The safe supply level exists when the strategic reserve level constitutes about 75 - 100% of the total carrying capacity of stored goods. A medium supply level exists when the strategic reserve level ranges between 50 – 75% of the total capacity for good storage. At this stage, the private sector will be asked to increase the storage rates and the government will provide supportive programs to ensure their compliance. The last stage, which required the intervention of the government, occurred when the strategic reserve is less than 50% of the total carrying capacity for goods storage, here, the government intervenes directly to import goods and raise reserve quantities to the target level (SAGO 2022a).

4.3.2 Measures Taken by the Commodity Abundance Committee to Improve Strategic Food Reserves in KSA

Usually, the CACO takes strong measures to sustain the strategic food reserve in the Kingdom during critical times. It usually directs SAGO, Saudi Agricultural Development Fund (SADF), and/or Saudi Agricultural and Livestock Investment Company (SALIC) to intervene in purchasing and/or financing the provision of needed commodities during critical times. For instance, in 2019, CACO has taken the following measures to ensure sustainable food reserve in the Kingdom (SAGO 2020):

- Increase fund allocation for purchasing local wheat production, and encourage Saudi investment abroad (The responsible authority is MEWA and SAGO).
- Finance soybeans import to support the private sector's stocks (The responsible authority is SADF).
- Finance maize import to support the private sector's stocks (The responsible authority is the Saudi Agricultural Development Fund).
- Start receiving private sector requests for financing barley import to support their stocks (The responsible authority is the Saudi Agricultural Development Fund).
- Coordinate with Indian partners to provide 10,000 tons of rice when needed (Responsible Authority is Saudi Agricultural and Livestock Investment Company (SALIC) (.
- Finance rice imports to support the private sector's stocks (The responsible authority is SADF).
- Finance the import of sugar to support the private sector's stocks (The responsible authority is SADF).
- Finance the import of red meat to support the private sector's stocks (The responsible authority is SADF).
- Finance the import of edible oil to support the private sector's stocks (The responsible authority is SADF).
- Import more than half a million cartons (equivalent to more than 183 million) eggs to balance the supply in the local market (Responsible authority is SALIC).
- Provide finance incentive for onion open cultivation operating costs (Responsible authority is SADF).
- Import 5,000 tons of onions to balance the supply in the local market (The responsible authority is SALIC).
- Provide incentive in financing the running cost of tomato production in greenhouses (The responsible authority is SADF).

4.3.3 Initiative to Develop an Early Warning System, Emergency Situations, and Manage Strategic Food Storage:

In 2020, SAGO continued its efforts to implement the initiative of developing an early warning and emergency system and managing strategic food storage through increasing silos storage capacities in the Kingdom's ports and developing a comprehensive strategic plan for strategic food storage (SAGO 2022a).

4.4 Grain Buying Modalities in KSA

According to the Honorable Cabinet Resolution No. (335) dated 19th of November 2007 (9/11/1428 AH), SAGO is responsible for meeting KSA needs from wheat and fodder barley. In doing so, SAGO applies a transparent policy to purchase wheat and fodder-barley from global markets, through offering tenders for international companies specialized in grain supply. This procedure is usually done through six major steps based on five main principles. The five principles are:

- Selection of the best specifications
- Qualification of international companies
- Qualification of teamwork from SAGO specialists
- Follow up on global markets developments
- Open tenders for international bidders.

The main six steps are (SAGO 2020).

- Identify specifications standard:
  - That guarantees the import of the best types of wheat available in the global market.
  - For imported fodder barley that guarantees to achieve the required level of quality
- Qualifying of international companies:
  - An electronic form is available on the SAGO website with all the necessary information on the registration requirements.
  - Receive registration requests via email, study the request, and respond by accepting or rejecting.
- Monitoring international markets:
  - Contiguous follow-up of global grain price developments in the most important global markets.
  - Daily and weekly brief reports on the developments in the global grain markets.
- Bidding:
  - Determining the required quantities in addition to sending invitations to qualified (registered) companies via fax in accordance with the Government procurement system.
  - Announcing the tenders in the local and international media.
- Receive offers and quotations:
  - Select bidders with least price that adhere to the specifications specified by the SAGO committee responsible for grain importations.
- Quality control of imported wheat and barley:
  - Qualification of (8) international companies specialized in examining grains in exporting countries' ports.
  - Taking samples of shipments as soon as they arrive at Saudi ports to ensure conformity with both specifications and inspection reports received from international inspection companies.

It is noteworthy here that KSA purchased wheat from both local and international markets. The total quantities of wheat import reached 29.9 million tons for the period 2008–2019 and the average price was 265.3 thousand USD/metric ton (995 thousand Riyals/metric ton) (Fig. 1). Moreover, the estimated yearly increase of wheat import during the period from 2008 to 2019 was calculated to be 219.36 metric tons, whereas, the annual prices (1000 USD)/metric tons showed a declining trend by 8.99 units/ annum.

In 2019, SAGO implemented the local wheat-purchasing program, within the framework of Cabinet Resolution No. (66) Dated 2nd March 2016 (22/5/1437 AH) to control KSA green-fodder cultivation. The resolution assigned SAGO the mission of purchasing wheat from qualified farmers who cultivate wheat in an area of less than 50 hectares. This program extends for five years; however, the maximum purchased quantity must be less than 700 thousand tons/year (General Food Security Authority 2023a, b). In this regard, it is worth mentioning that the purchased quantity of wheat in 2019 was 202.179 thousand tons bought from 930 farmers scattered almost all over the Kingdom. However, in 2021 the purchased quantity increased substantially to reach 573.43 thousand tons, but it declined in 2022 by 6.5% (General Food Security

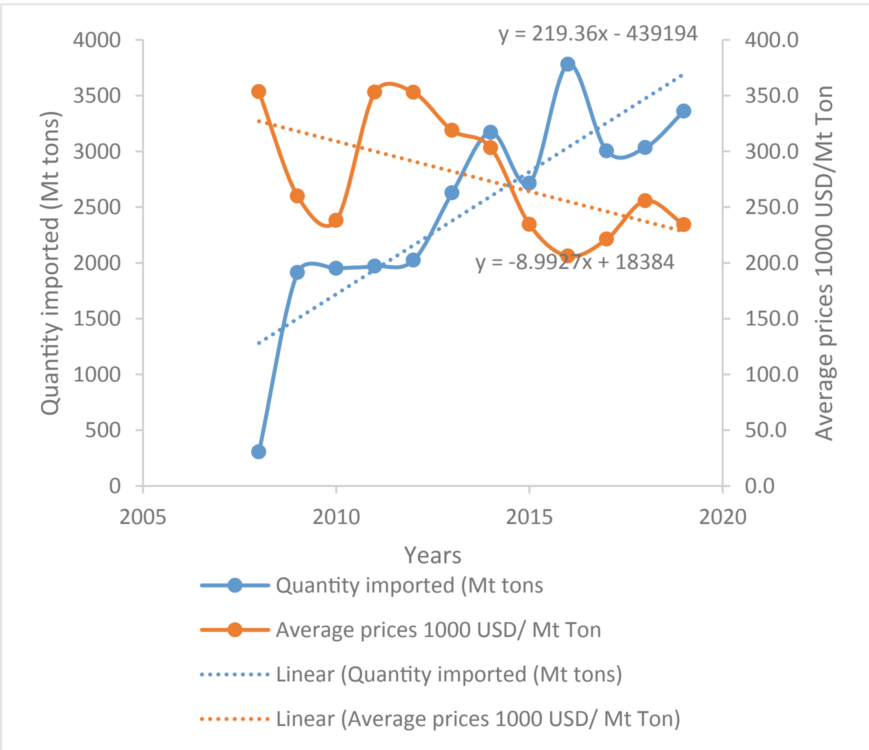


Fig. 1 Total quantities of imported wheat (tons) by SAGO and their average prices for the period 2008–2019. *Source* Calculated by the Author from data collected from SAGO (2020)

Authority 2023a, b). It is important to note here that the local wheat purchased is considered one of three sources that SAGO depends on for sustaining the food security in the Kingdom. Other sources are purchasing 20% of the total wheat purchased from Saudi investors abroad, in addition to the international tenders offered by the SAGO and in which companies compete (General Food Security Authority 2023a, b). Such policy has resulted in a substantial increase in the area and production of wheat locally by 236.9 thousand tons/year and 32.2 hectares/year, respectively (Fig. 2).

On the other hand, SAGO officially started the task of importing fodder barley in October 2016. In December 2016, it signed contracts for importing 945 thousand tons of fodder-barley to be supplied during the first quarter of 2017. Moreover, in 2017, it signed contracts for importing 7.33 million tons as an additional amount to the previously contracted quantity of 1.02 million tons by the Saudi Grains and Fodder Holding Company (SGAF) (Fig. 3).

In 2018, SAGO signed contracts for importing 8.74 million tons of fodder-barley; however, in 2019 the imported quantity decreased by 39.5% to 5.29 million tons due to the good rainy season. The average prices for the imported fodder were 806 and 771 Riyal/ton in 2018 and 219 respectively, (SAGO 2020).

SAGO has taken strict measures to ensure the quality and conformity of wheat and barley to the specifications standard.

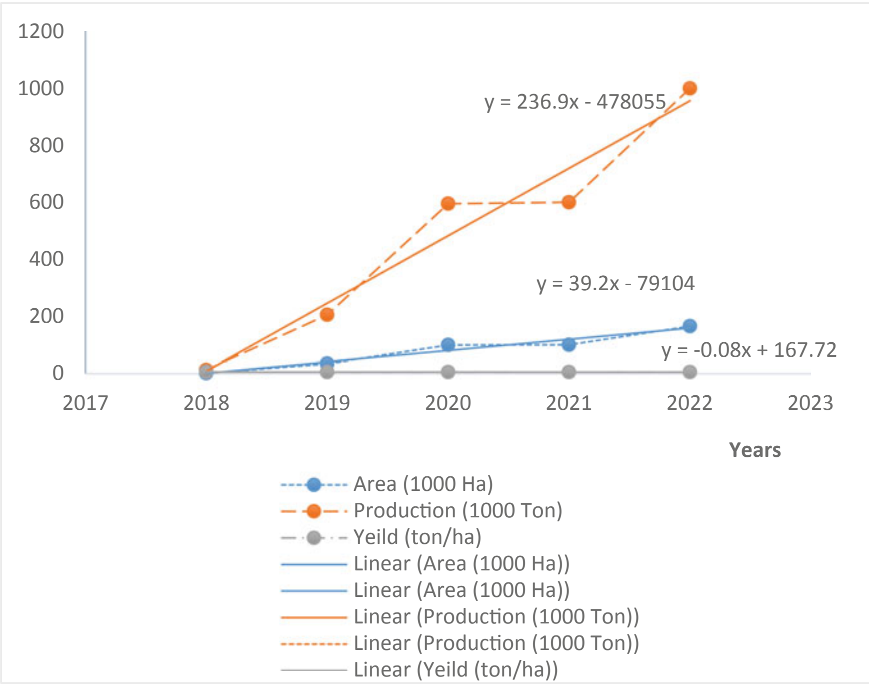


Fig. 2 Wheat cultivated area (Hectare) and production (000 tons) KSA for the period 2018–2022. *Source*:Calculated by the author from data collected from SAGO annual report 2019 (SAGO 2020)

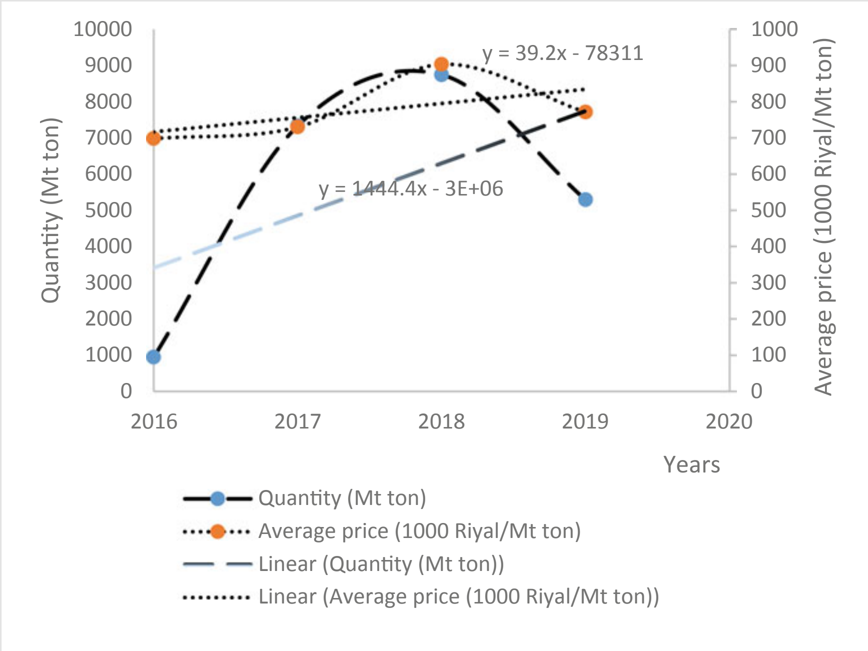


Fig. 3 Total quantities of imported fodder-barley (tons) by SAGO and their average prices for the period 2008–2019. *Source* Calculated by the author from data collected from SAGO annual report 2019 (SAGO 2020)

SAGO Steps for quality assurance (SAGO 2020):

- Selection of the best standard to guarantee the import of high Quality of wheat and barley.
- Qualifying international companies (as neutral companies) specialized in examination to check for wheat and barley at shipping ports
- Taking samples from each imported grain shipment to be examined by the SAGO laboratories immediately after the arrival of the imported ships to KSA ports (before unloading).
- Taking other samples from the shipment during the unloading process to be examined at SAGO laboratories (whether central or branch laboratory).
- Monitoring the quality of stocks during the storage period through implementing the ventilation, rotation, and fumigation processes in accordance with an approved schedule.
- Monitoring the quality of milling companies' products (flour), through monitoring changes in flour properties, and examining bakeries' complaints.

4.5 SAGO Selling and Distribution Practices

SAGO, by virtue of its jurisdiction, is responsible for securing the local market's needs for wheat and fodder-barley, by meeting milling companies' (four) wheat purchase requests and providing barley units (sales and distribution) with their required quantities (SAGO 2020).

In 2020, the Saudi government issued a decree assigning the responsibility of barley importation and distribution to the private sector. The decree became effective at the end of March 2021. According to USDA (2021), such a Saudi decree coupled with Kingdom revisions of its animal feed subsidy program policy in 2020 is expected to significantly reduce the quantity of barley imported and consequently affect U.S.A barley exports. It is important to note that, in 2019 the total imported quantity of barley was 3.9 billion tons, which is worth 3.31 billion Saudi Riyals (General Authority for Statistics 2020). The main barley exporting countries to KSA were Argentina, Russia Federation, and Ukraine with values of 763, 734, and 575 million Saudi Riyals, respectively.

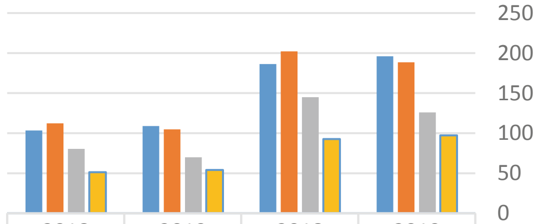
Pertaining to wheat, in 2019, the total quantities of wheat sold by SAGO to the four milling companies amounted to 3.38 million tons of high-quality durum wheat (12.5% protein), compared to 3.48 million tons in 2018 (2.9% decreased). SAGO sold wheat to the four milling companies at a subsidized price of 180 riyals/ton, in order to maintain the subsidized selling prices of flour and wheat derivatives in the local market (Fig. 4). However, in 2021 Saudi Arabia removed the subsidy from wheat and fodders (SAGO 2022b).

On the other hand, in 2019, the total quantities of fodder-barley sold to distribution stations amounted to 6.452 Million tons compared to 7.996 Million tons in 2018 (a 19.3% decrease). The main fodder-selling stations are Jeddah, Jamoum, Shumaisi, Yanbu, Jazan, Duba, Dammam, and Jubail (SAGO 2020).

4.6 Production and Storage Capacity of Flour Mills Companies in KSA

The Mills sector is one of the new sectors that entered the Saudi economy after completing its privatization program, in line with the directions of the Kingdom's Vision 2030 and the National Transformation Program emanating from it. The vision aims to develop the contribution of the private sector in the Saudi economy through liberalizing the state-owned mills and making them available to the private sector investment both Saudi and foreigners (SAGO 2022c). SAGO moved its activities towards targeting four areas of the structure: transfer of assets, employees, and data, in addition to defining the legal framework (SAGO 2022c).

The Council of Ministers identified the silos and mills sector among the sectors targeted for privatization in order to increase competitiveness, improve productivity and stimulate investment. In 2017, four mill companies were established. In 2020,



	2018 Sold Quantity (10000 Tons)	2019 Sold Quantity (10000 Tons)	2018 Prices (Million Saudi Riyals)	2019 Prices (Million Saudi Riyals)
The 1st milling company	103.4	108.9	186.28	196.072
The 2nd milling company	112.3	104.8	202.17	188.598
The 3rd milling company	80.5	70	145.009	125.961
The 4th milling company	51.4	54	93	97.187

Fig. 4 Quantity of sold wheat (10 thousand Tons) to the four milling companies in KSA and prices (Million Saudi Riyals) in 2018 and 2019. *Source* Drawn by the Author from SAGO 2020b data

two companies out of the four milling companies were privatized: the First and Third companies. Similarly, in 2021, the other two companies were privatized. The First, Second, Third, and Fourth Milling Company has been awarded to Raha AlSafi Consortium; AlRajhi, Ghurair and Masafi Consortium; AlAjlan, Nadec, AlRajhi, and Olam Consortium; and Allana, AlOthaim and United Feed Consortium, respectively (SAGO 2022c).

The total available capacities for flour production for the four milling companies at the end of the year 2019 amounted to about 15.15 metric tons of wheat/day, and the total production capacities for the fodder factories were 3.2 metric tons/day, while the total operational storage capacities were 735 metric tons of wheat (SAGO 2020).

5 Conclusion and Prospects

The KSA, represented by MEWA, has developed a comprehensive national food security strategy, the supervision and execution of which was assigned to the SAGO, which is currently known as GFSA. In this regard, SAGO was assigned the responsibility of managing a strategic food reserve and early warning system including buying, importing, storing, and distributing the main cereals crops, particularly wheat, and fodder-barley, however, in recent years, privatization took place and SAGO role is confined to the monitoring and supervision. Additionally, in order to facilitate the work, the commodity abundance committee was formed, from a different identity including SAGO, with the responsibility of daily monitoring the levels of strategic reserve and stabilizing food commodities supplies. Undoubtedly, KSA has a well-established flour mills sector, storage capacities, and distribution system. Likewise, it has a well-defined food reserve system that delineates authorities and responsibilities. In this regard, it is worth noting that the kingdom depends on three food sources to sustain its strategic food reserve at a safe level: local production, investments abroad, and imports. Pertaining to local production, the KSA has a clear policy for improving local production and achieving self-sufficiency from certain products. Moreover, the commodity abundance committee has clear procedures that can be used during critical times. For instance, the commodity abundance committee liaises with Saudi Agricultural Development Fund, Saudi Agricultural and Livestock Investment Company (SALIC), and MEWA in the intervention for maintaining the strategic stocks at a safe level through the provision of fund, support, and/or sometimes directly purchasing of commodities when their strategic reserve is less than 75% of the total carrying capacity of goods storages. It is also evidence that food security policies that were implemented by the Kingdom have succeeded in sustaining food security during critical times of COVID-19.

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Chapter 18
Contribution of Higher Education Institutions to Food Security: The Case of King Faisal University

Amal Saeed Abass, Ishtiag Faroug Abdalla, and Adam E. Ahmed

Abstract Higher education institutions play a vital role in several areas related to achieving food security. These areas include increasing agricultural production and productivity, innovating modern agricultural technologies, improving agricultural practices, and enhancing the quality of food products. This particular chapter aims to discuss the role of higher education institutions in Saudi Arabia, which comprises specialized colleges and research centers focused on achieving food security. The contribution of these institutions will be assessed based on their fundamental higher education activities such as teaching and learning, scientific research, and community partnership. Additionally, the chapter will address the establishment of strategic partnerships with government institutions and the private sector in the field of food security, including plant and animal production, and water. To highlight the initiatives related to food security, the chapter aims to illustrate efforts to organize and implement conferences, workshops, and training courses. In particular, the chapter will emphasize King Faisal University as it has adopted its institutional identity as "Food Security and Environmental Sustainability".

Keywords Food security · Food loss · Food insecurity · Initiatives · Research chairs · Research center · Sustainability · Universities

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1 Introduction

Higher education institutions have a significant role in achieving food security. Food security is attained through conducting scientific research and graduating specialized individuals in areas related to food security, as well as through community partnerships. Higher education institutions are involved in conducting scientific research and presenting innovative technological initiatives that benefit the agricultural sector and its supporting industries. They also study the causes and determinants of food security and contribute to developing appropriate policies and solutions to address obstacles related to food security. Additionally, higher education institutions are responsible for graduating specialized technical professionals involved in food production processes throughout the entire supply chain. These institutions also collaborate with stakeholders involved in food production, storage, processing, and handling. Furthermore, higher education institutions play a crucial role in adapting to the impacts of climate change in order to establish sustainable food systems. In addition, higher education institutions are actively involved in community outreach and advocacy activities to raise awareness about the importance of food security and promote sustainable and equitable food systems.

Universities work in collaboration with the surrounding communities and are responsive to their needs. Various research and studies indicate the significant importance of universities in achieving economic development, which in turn leads to an increase in the welfare of societies. Higher education institutions provide benefits that are not limited to only student learning but also extend to serving societies in multiple fields (Farnell 2020). Furthermore, analysing the advantages of competencies acquired from higher education institutions is considered to be a crucial source of changing people's lives (Pee and Vullueh 2020). Presently, the importance of universities in constructing a knowledge economy is recognized by higher education.

Saudi Arabia has embraced the trend towards a knowledge-based economy by focusing on its higher education sector. The country's academic institutions have played a pivotal role in transforming its economy and achieving development and economic growth (Salem 2014). Higher education institutions are a crucial factor in a country's progress, as they offer educational activities, innovations, services, consultations, and capacity building that enable the qualification of human cadres. For example, higher education institutions can increase the well-being of societies by analysing cases of food insecurity and implementing appropriate intervention measures. They can also identify means and methods for achieving self-sufficiency in food commodities, as well as how to properly store, manufacture, and transport them from production areas to consumption areas. Additionally, higher education institutions can develop knowledge-based agricultural policies and regulations (Abunasser et al. 2022).

According to the Food and Agriculture Organization (FAO) of the United Nations, food security means that "all people should have access to enough safe and healthy food that meets their dietary needs and preferences for an active and healthy life" (Alsarawi et al. 2022). This definition shows that food security is crucial for the well-being of society and that food insecurity can have negative effects on national security. It also highlights the importance of the agricultural sector and food industries in helping to achieve food security.

Achieving both the assurance of sufficient food supply and the protection of the environment necessitates endeavours at both the local and global scales. Academic institutions have a significant role to play in this framework based on their objectives and principles. This involvement can encompass advances in academic learning, creating awareness among students about the concepts and necessities of food security, introducing modern agricultural innovations, enhancing the skills of individuals engaged in food security work, contributing to the development and implementation of policies and strategies concerning food security, and conducting specialized scientific research in this field. These endeavours can assist in resolving food security issues at the national, local, and individual household levels (Abunasser et al. 2022).

2 The Role of Universities in Promoting Food Security in Saudi Arabia

Saudi Arabian universities have played a crucial role in enhancing food security within the country. This achievement has been made possible through the establishment of specialized colleges and research centers that focus on matters related to food security. A few instances of these institutions are provided in Table 1.

King Saud University (KSU) was established with the objectives of disseminating knowledge in Saudi Arabia, establishing a foundation of scientific expertise, and maintaining a competitive advantage over other universities in the field of sciences to drive innovation. KSU has many colleges with various specializations, one of which is the College of Food and Agricultural Sciences. The college, founded in

Table 1 Universities associated with food security in the Kingdom of Saudi Arabia

	KSA Universities related to Food Security
1	King Saud University
2	King Abdul Aziz University
3	King Abdullah University of Science and Technology
4	King Faisal University
5	Qassim University
6	Jazan University
7	Northern Border University
8	King Abudellaziz City for science and technology

Source Universities websites. KSU (2023a, b), KAU (2022), KFU (2023), KAUST (2015), Qassim University (2012), Jazan University (2023), Northern Border University (2023), and KACST (2020)

1965, was the first institution of agricultural sciences in the Arabian Peninsula to accept and graduate agricultural specialists, engineers, and researchers in the fields of agricultural, ecological, and food sciences. Currently, it consists of eight scientific departments specialized in agricultural, food, and environmental sciences (KSU 2023a, b).

The King Abdulaziz University was founded in 1967 as a private institution. It consists of various colleges that specialize in food security and aim to promote awareness about related issues. These colleges include the Faculty of Environmental Studies, the Faculty of Marine Studies, and the Faculty of Economics and Administration.

King Abdullah University of Science and Technology (KAUST) is an international research university that focuses on science and technology. It has exceptional faculty, engineers, scientists, and students from around the world. The university is home to 10 research centers that work on issues related to food, energy, and the environment. One of KAUST's research centers is the Water Desalination and Reuse Center (WDRC), which develops new methods and strategies for water desalination. The center's capabilities range from laboratory research to the transfer of technologies and large-scale water production. The WDRC aims to share knowledge of scalable approaches, such as using solar energy or wasted heat as an energy source. Another important center at KAUST is the Center for Desert Agriculture (CDA), which aims to improve plants' ability to survive in the hot, salty desert environment and droughts. CDA researchers use genetic, genomic, and epigenetic techniques to create plants that can tolerate stress and apply their findings directly to crop plants in the field. The center offers various programs, including Bioscience, Environmental Science, and Plant Science (KAUST 2015).

Al-Qassim University, located in the Al-Qassim Governorate, is renowned for its agricultural production, earning it the reputation of being the food basket of the Kingdom of Saudi Arabia. The region heavily relies on agriculture, specifically plant and animal farming, as the main source of income and to ensure food security for millions of people in Saudi Arabia and the Middle East. There is a strong emphasis on applied scientific research in the area, with the aim of preserving the health and quality of agricultural outputs. Researchers at the Faculties of Agriculture and Veterinary Medicine are dedicated to finding solutions to challenges that threaten crop and livestock production, with the goal of sharing their knowledge with partners and stakeholders at regional and global levels. Moreover, academics at Qassim University actively strive to publish credible scientific research in esteemed scientific journals, while also creating and disseminating awareness messages to farmers in order to enhance production and maintain the quality and safety of food products (Qassim University 2022).

The Environmental Research Center at Jazan University conducts exceptional scientific research in environmental studies and provides scientific recommendations to external partners. Additionally, it establishes and enforces nationwide and global agreements in the field of environmental disciplines (Jazan University 2023).

Northern Border University holds a unique position in higher education in Saudi Arabia. Its strategies are influenced by the region's culture, history, and location.

The university consists of several colleges, including the Faculty of Family and Consumer Sciences, which houses a Department of Nutrient and Food Sciences. The college aims to equip students with the necessary skills to work in the nutrition field, thus creating more opportunities for female professionals to educate society on the importance of nutrition. Moreover, providing female students with food science skills enhances job prospects for women in food production and processing (Northern Border University 2023).

The King Abudellaziz City for Science and Technology (KACST) has expressed that they believe scientific research and technological advancements are crucial elements for the continued economic growth and national development of the Kingdom of Saudi Arabia (KACST 2020). They also inform that they handle and oversee the following activities:

(a) Supporting the National Research, Development, and Innovation Strategy: The King Abdulaziz City for Science and Technology (KACST) has prepared a national plan for science, technology, and innovation called the National Industrial Development and Logistics Program (NIDLP). It also provides scientific support services for universities and research centers. The KACST is in charge of the National Science, Technology, and Innovation Strategic Plan (NSTIP). The KACST plays a crucial role in implementing the plan as it leads the guidance committee and issues report on governing regulations and key performance indicators. The NSTIP consists of eight strategic programs, which are further divided into projects to be completed by both public and private sectors in Saudi Arabia. The purpose of this is to ensure the Kingdom's vision is realized by organizing the administrative, financial, and technical procedures of NSTIP. Additionally, it aims to define the responsibilities and commitments of all involved parties in the implementation of the projects and programs.
(b) Technological Support: Technical support includes providing internet services through the Saudi Research and Innovation Network (Maeen), as well as offering technical services and electronic and security archiving.
(c) Research and Development: KACST carries out research and development projects in 15 vital sectors that contribute to economic growth and sustainability.
(d) Innovation Support: KACST supports and develops the industrial innovation centers program, as well as enhancing the work of business incubators, accelerators, and the Industry.
(e) The mission statement of KACST declares that its goal is to invest in scientific research and technological advancements to contribute to the national development in the Kingdom. They seek to accomplish this through the following objectives:
(f) a. Providing support for scientific research and technological development. b. Conducting applied scientific research and technological development. c. Coordinating national activities in the fields of science, technology, and innovation - Strengthening local and international partnerships for the transfer, adoption, and development of technology, and d. Providing consultations, services,

and innovative solutions. e. Investing in the development of technology and its commercial applications.

(g) In addition, the King Abdulaziz City for Science and Technology (KACST) operates a Water Quality Laboratory that contains various analytical tools used to detect the quality, usability, expiration, and concentration of elements in the water. The laboratory also ensures that the water meets the standards set by the World Health Organization. Some of the tests carried out in the laboratory include detecting ketones, heavy metals, anions, and organic content, and conducting primary physical analyses. The laboratory offers a range of physical and chemical tests for water. Numerous higher education institutions are dedicated to addressing food security. For example, researchers at King Saud University (KSU) are involved in a research project with the objective of creating sustainable crop production systems for arid regions. Their focus is on utilizing advanced irrigation technologies such as drip irrigation and subsurface irrigation. Additionally, they aim to cultivate crop varieties that can thrive in the local environment, withstand drought, and tolerate high temperatures. Similarly, researchers at King Abdulaziz University (KAU) are working on a project aimed at improving soil fertility and crop productivity. Their investigations involve exploring the use of organic amendments and integrated nutrient management practices. Furthermore, they conduct field trials to evaluate the effectiveness of organic fertilizers such as compost and vermicomposting. They also aim to develop customized nutrient management guidelines for specific crops. At King Faisal University (KFU), researchers are undertaking a project focused on developing sustainable livestock production systems suitable for the local environment. Their objective is to enhance food security and improve livelihoods in rural areas. This project includes studying the use of local feed resources such as date palm leaves and by-products. Moreover, they are developing breeding programs for local livestock breeds that can thrive in harsh climatic conditions. Researchers at King Abdullah University of Science and Technology (KAUST) are dedicated to enhancing water-use efficiency in agriculture. They are involved in a research project that incorporates the utilization of sensors and precision irrigation technologies. Their aim is to create algorithms that optimize irrigation scheduling based on real-time data on soil moisture and weather conditions. Additionally, they are testing these technologies on a variety of crops and soil types. The University of Tabuk is also engaged in a research project focused on developing sustainable aquaculture practices for freshwater fish species in the region. This project involves studying the use of locally available feed resources, implementing breeding programs for local fish species, and adopting recirculating aquaculture systems to reduce water usage and waste in fish production.

3 King Faisal University

King Faisal University (KFU) has positioned itself as a prominent research institution in the Kingdom due to its highly qualified researchers, well-trained laboratory technicians, and well-equipped research facilities and laboratories. According to KFU (2023) the university's qualitative research centers, such as the Agricultural and Veterinary Training and Research Station, the Deanship of Scientific Research, and the Institute of Research and Consultation, are continuously improving their strategies, programs, and activities to attract exceptional researchers, secure additional funding, participate in renowned research projects, and promote international collaboration and partnership. The ultimate goal is to elevate the university's research programs to meet or exceed internationally recognized standards. Based on this revamped research concept, the university aims to excel in specific areas, including environmental sustainability, natural resource management, medicine, healthcare, agriculture and food resources, engineering, biotechnology, nanotechnology, and applications of material science. KFU intends to advance knowledge through innovative research and scholarship across various academic disciplines and graduate studies, all within a high-quality research environment.

The tools needed to accomplish this objective are as follows:

1. Increase external funding by seeking more research opportunities through external grants.
2. Establish the necessary infrastructure, including buildings, laboratories, manpower, and support services, to facilitate scientific research.
3. Replace the paper-based system for applying and managing research grants with electronic forms and signatures.
4. Create a supportive environment for new researchers and high-achieving academics.
5. Serve the academic community through an integrated, distinguished, and responsive research department.
6. Manage financial resources to effectively support research capabilities and infrastructure.
7. Take advantage of the diverse range of disciplines within the university's research base to develop a robust interdisciplinary research program.
8. Enhance opportunities for starting interdisciplinary research collaborations.
9. Educate faculty members and researchers on the process of registering patents and scientific discoveries.
10. Prioritize faculty retention by safeguarding their fields, improving their income, and facilitating their research capabilities.
11. Expand the number of postgraduate programs available.
12. Attract exceptional students and promote their loyalty to the institution.
13. Increase the enrolment of postgraduate students by enhancing the capabilities of postgraduate programs.
14. Introduce doctoral programs in areas of strong research focus at the university (KFU 2023).

The Research and Consulting Institute at King Faisal University plays an important role in connecting the community with experts in various development fields. Its goal is to find solutions to social or scientific problems, whether they pertain to knowledge, business, or industry, leading to sustainable or short-term development. The Institute aims to increase the return on investment in human and material resources and infrastructure at King Faisal University through contract research, innovative consulting research, analytical and technical services, and training for both the public and private sectors. Its objective is to help these sectors better address significant challenges, improve the quality of their services and products, increase their performance speed, and maximize their returns and revenues. According to Al-Ohali (KFU 2020), King Faisal University has abundant resources that allow it to excel at national and regional levels, reflecting its long history and philanthropic heritage. As the country undergoes a transformation in its development process, it is crucial to invest in and build upon these resources, reaching broader horizons based on the university's established scientific structure and respected research institutions. The ultimate goals are to achieve good governance and adhere to the Kingdom's 2030 vision. That is why King Faisal University has introduced its 2020–2024 strategy, outlining its future roadmap for the next five years and anticipating growth and excellence. The ambitious strategy will focus on improving teaching, learning, and scientific research processes, fostering community partnerships, and establishing a comprehensive system to support innovation and business development at the university. Through these efforts, they aim to enhance the university's governance, administrative effectiveness, expenditure efficiency, and financial stability, while also fostering strategic partnerships at the national and global levels to achieve mutual goals. The education sector in Saudi Arabia is currently undergoing a transformative phase, as plans and programs aligned with the Kingdom's 2030 vision are being implemented. King Faisal University's 2020–2024 strategy is a response to this vision, and in the next five years, the institution will experience significant growth, benefiting both its internal and external communities. The university possesses the necessary flexibility and qualified human capabilities to adapt to future changes and developments, enabling it to adjust its plans accordingly.

The strategic goals of KFU are as follows: 1. Developing future-oriented educational outcomes that are competitive both locally and internationally, despite economic and developmental transformations. 2. Maximizing the benefits of research and aligning research activities with the national goals and aspirations of the university's identity and the Kingdom's vision. 3. Continuously improving the university's educational system and focusing on community engagement, particularly in areas that mutually enrich both the university and the community. 4. Establishing and cultivating a system for university innovation and business development, enhancing its economic capacity. 5. Directing resources and capabilities towards providing exceptional university experiences that meet student expectations. 6. Adopting best practices to enhance institutional performance and promote effective business governance. 7. Achieving optimal financial performance through the efficient use of resources and capabilities. 8. Selectively developing partnerships and alliances that enrich university experiences and create opportunities for integration and strategic synergy (KFU 2020).

3.1 The Institutional Identity of King Faisal University: Food Security and Environmental Sustainability

Based on Saudi Arabia's Vision 2030 and its development goals, especially in the field of education, KFU aims to become a leading university in both local and global contexts. KFU's goal is to establish a dynamic and forward-thinking learning environment that promotes productivity and innovative research. The university is particularly focused on contributing to national objectives in food security and environmental sustainability (KFU 2019). These key issues are central to KFU's societal contribution, and the institution aims to build upon the practices and research capabilities of its predecessors to address challenges such as drought, desertification, and related problems in these areas. KFU has specialized research centers in food security and environmental sustainability that serve as platforms for ground-breaking research and innovation. The university also aims to establish partnerships with policymakers and the private sector to enhance its resources and impact in these domains. Additionally, KFU plans to leverage its investment capabilities and the Al-Ahsa Oasis and Agribusiness incubator to support the commercialization of its research products and contribute to environmental preservation and food security. The university intends to reduce campus carbon emissions and energy consumption and promote sustainable landscaping activities as examples for students to follow in order to protect the environment and support food security. KFU has made food security and environmental sustainability an integral part of its institutional identity. This directly affects the university's functions through various methods, including but not limited to: 1. Focusing research efforts on projects related to food security and environmental sustainability and establishing crucial research partnerships to support these endeavours. 2. Implementing targeted development and investment projects in the fields of food security and environmental sustainability while promoting interdisciplinary collaboration to share technologies and expertise and redefine relevant industries. 3. Integrating concepts of food security, environmental sustainability, and related support areas into educational programs. 4. Creating, implementing, and investing in a wide range of partnerships to raise community awareness about food security and environmental sustainability.

According to KFU (2019), the university has been motivated by various internal and external factors to position itself as a provider of food security and environmental sustainability. Internally, the university takes pride in its specialized knowledge and expertise in agricultural and food sciences, veterinary medicine, and other supportive colleges. Additionally, the university has expanded its research centers to include areas such as palm and dates, camel, water, fisheries, birds, and bees. The university has also formed strategic partnerships with public and private sector organizations and established research agreements with international universities in the fields of food security and environmental sustainability. Furthermore, the university has encouraged investment and entrepreneurship through initiatives like the Al-Ahsa Oasis Project for Innovation and Technology and the Agribusiness Incubator and Entrepreneurship Center. Externally, the university's positioning is in line with the Kingdom's Vision 2030, which aims to develop food security and sustainable use of water resources. The university acknowledges the global and local challenges related to food security and environmental sustainability. It aligns with national strategies and initiatives in these areas, as well as with the National Industry and Logistics Development Program, particularly in the pharmaceutical and renewable energy industries. The university's position is also in line with the Sustainable Development Goals (SDGs) set by the United Nations. The geography and topography of Al-Ahsa Governorate, along with its environmental implications, further support the university's positioning. The university has also launched several transformative initiatives to promote food security and environmental sustainability. Finally, the university recognizes the importance of a strong market for agricultural technologies and their applications to support food security and environmental sustainability in the Kingdom (KFU 2019).

The domains relating to food security and environmental sustainability at KFU consist of 8 areas: water, agriculture, environment, management, technology, health, transportation and logistics, manufacturing, and energy. Currently, the world is dealing with a significant challenge caused by a shortage of water, which is particularly difficult for the Kingdom due to its land being mostly covered in desert. Therefore, it is important to study techniques, legislation, and administrative models that can improve water resources and maximize their benefits. Additionally, a better understanding of groundwater is needed, which requires studies on available water reservoirs and aquifers in the Kingdom. Collaboration with relevant authorities is also necessary to improve techniques for seawater desalination and water recycling. Furthermore, the focus will be on studying the best methods of storing and distributing water in desert environments to ensure the sustained availability of resources for human consumption, agriculture, and industry in both the present and the future.

Agriculture plays a vital role in attaining food security. This can be achieved by practicing diverse and sustainable agricultural production. To accomplish this objective, it is essential to enhance the production of plants, animals, and fisheries in terms of both quantity and quality by making the best possible utilization of natural resources. This includes the control of pests and reduction of crop losses. In order to maximize production, various areas such as innovative agriculture, sustainable agriculture, fish farming, and other related fields must be taken into consideration. It is worth noting that Saudi Arabia is faced with numerous environmental challenges, including desertification, decreasing vegetation, and environmental pollution. Therefore, efforts should be made to identify potential solutions to these challenges while considering the local environment and limitations. This includes understanding the environmental impact of desalination and finding ways to manage and preserve the marine environment, particularly the Arabian Gulf. Additionally, the agricultural sector aims to study and appreciate desert environments, such as the Empty Quarter and its surrounding areas. Furthermore, it will explore ways to utilize the environment for tourism while ensuring the preservation of our environmental conservation efforts. The approach in the agricultural sector involves directing teaching and learning activities towards incorporating an environmental aspect for students, assisting researchers in studying the necessary technologies and disciplines for environmental protection, and participating in community activities that contribute to environmental preservation. Moreover, effective strategies will be developed to optimize the management of environmental resources, support conservation programs for plants and animals, and promote a green economy.

The importance of technology cannot be overstated when it comes to achieving food security and enhancing environmental sustainability. Drones are a prime example of a technological innovation that can greatly improve the monitoring of environmental changes as well as the investigation of plant and animal diseases. Modern water technologies such as desalination and recycling techniques have the potential to maximize the availability of water for various purposes and optimize the utilization of resources. By improving water distribution techniques, agricultural costs can be significantly reduced while ensuring long-term sustainability. Additionally, the development of new agricultural techniques for seawater and fish farming holds great promise in improving food security while also maintaining environmental sustainability, opening up a world of possibilities. The domain of health is a crucial indicator of the progress made by any community, and progress can be achieved through a healthy diet and a favourable environment. Health is intricately connected to nutrition and applies not only to humans but also to plants, animals, and fisheries. The research in the field of health aims to develop robust health and food policies, as well as create clear disease maps. Moreover, the development of new medical systems will ensure the sustainability of livestock, thereby enhancing the efficiency of therapeutic products linked to our vital agricultural resources. These new systems may also help in combating obesity and diseases that have been disproportionately affecting our nation in recent times. Furthermore, the utilization of recent advancements in psychology can encourage habits that contribute to maintaining health and food security, alongside promoting environmental sustainability.

The transportation and logistics industry plays a crucial role in achieving food security by efficiently transporting and storing food in designated locations to preserve it. This field involves researching methods to transport crops and food products with the goal of minimizing waste throughout all stages of food handling, from production to consumption. This can be achieved by improving the effectiveness of logistics services and reducing their expenses. Investing in logistics solutions will help to ensure a smooth operation of the food supply chain. Manufacturing is also crucial for achieving food security. Robust food-manufacturing facilities that are backed by rigorous research and development are necessary in order to achieve food security. This involves developing advanced manufacturing solutions for both plant and animal products, as well as natural resources. It is equally important to promote manufacturing technologies that protect the environment while safeguarding plant and animal products. Saudi Arabia has access to various natural energy sources, including oil, gas, and renewable energies. Among all the energy options, KFU will focus on renewable energies, particularly bioenergy resources like algae, and aim to integrate them into different agricultural and water systems. This integration will help to ensure a stable food supply while also protecting the environment. Moreover, efforts will be made to explore technical and administrative solutions that can reduce the energy required for the production, manufacturing, and distribution of different types of food (KFU 2019).

KFU has taken a number of actions to establish itself as a leading institution in the advancement of food security and environmental sustainability. One approach that the university is taking to achieve this goal is through its research programs. KFU has established various research centers and institutes that focus on agriculture, food science, and environmental sustainability. These research programs are aimed at finding innovative solutions to the challenges related to food security and sustainability in the region. The university's research focuses on identifying sustainable agricultural practices, developing new resilient crop varieties to combat climate change, and enhancing food processing and preservation technologies. KFU is also dedicated to promoting food security and environmental sustainability through its educational programs. The university offers undergraduate and graduate programs in agricultural sciences, food science, and related fields. It provides hands-on training and experiential learning opportunities to students, aiming to develop a skilled workforce that can contribute to a sustainable and secure food supply in the region. In addition to research and education, KFU engages in community outreach efforts linked to food security and environmental sustainability. The university collaborates closely with local communities and stakeholders, working together to identify and address food security challenges and promote sustainable agricultural practices. KFU also partners with government agencies and non-governmental organizations (NGOs) to develop policies and programs that support food security and environmental sustainability within the country. Furthermore, KFU has implemented various sustainable practices on its own campus, including the use of renewable energy sources, water and energy conservation, and waste reduction and recycling programs. These practices serve as a model for the wider community and demonstrate the university's dedication to environmental sustainability.

3.2 College of Agricultural and Food Sciences at KFU

The College of Agricultural and Food Sciences (CAFS) has been in existence since King Faisal University was established in 1975. It was one of the four colleges at KFU and was among the first colleges on which the university was founded. The vision of the college is to be a leader locally and regionally in enhancing agricultural knowledge, developing people's abilities, and supporting food security and environmental sustainability. The College of Agricultural Sciences consists of seven departments closely related to food security, which are as follows: 1. The Department of Agribusiness and Consumer Sciences specializes in both theoretical and practical applications related to economic theories, as well as management and economics in the basic sciences. This department is responsible for various tasks, including agricultural production and business associated with the production of food industries and agricultural product derivatives. 2. The Department of Animal and Fish Production focuses on the theoretical foundation and practical implementation of animal, poultry, and fish production sciences. Its goal is to develop national professionals who can work within governmental institutions, institutes, and academic/research bodies related to animals and fishery. 3. The Department of Environment and Agricultural Natural Resources teaches sciences related to the natural ecosystems available in Saudi Arabia and the surrounding conditions. The department aims to provide students with fundamental concepts related to the environment and the preservation of the environment and its components to prevent deterioration and pollution, thus ensuring its productive capacity. 4. The Department of Agricultural Biotechnology focuses on teaching basic sciences related to cell and tissue culture, molecular genetics, gene modification, protein biosynthesis, and the sequencing of amino and nucleic acids. The aim is to develop modern technologies to enhance agricultural production and increase the efficiency of food sources, thereby contributing to global food security. The department follows environmental safety standards and adheres to ethical and social responsibilities. 5. The Department of Arid Land Agriculture focuses on teaching basic sciences related to horticultural sciences, crop sciences, and plant protection sciences. The goal is to improve plant production, expand its geographical coverage, and safeguard it against pests and diseases. 6. The Department of Food and Nutrition Sciences teaches basic and applied sciences related to the field of food, including preservation, processing, evaluation, analysis, and topics related to individual and community nutrition. 7. Lastly, the Department of Agricultural Systems Engineering specializes in theoretical and applied studies related to utilizing engineering science and technology to develop and operate technical systems that address agricultural problems and enhance agricultural industrialization. The department also aims to enhance production levels in terms of both quantity and quality, while reducing effort and cost (CAFS 2023a, b, c).

3.2.1 Research Centers and Units at KFU and CAFS

At KFU, there are numerous research centers and specialized units that are relevant to food security. These centers include the Center of Research Excellence in Date Palm. The center's vision is to become a leading and distinguished center at the local, regional, and global levels, achieving scientific and research value in the fields of date palm and date science. This will contribute to ensuring food security and environmental safety. One of the main objectives is to establish a distinguished scientific foundation and provide a stimulating environment for conducting research and training researchers in the field of date palms and dates. This effort aims to fulfil the university's role in achieving food security and environmental sustainability (Center of Research Excellence in Date Palm 2023). Additionally, the Fish Resources Research Center was established in 2006 to undertake research, studies, and consultation services related to the exploitation and development of marine resources through capture fisheries. The center also aims to enhance the knowledge of individuals interested in fisheries matters by expanding networking and collaboration with the private sector through technical workshops and courses. It is the leading research center in this field (Fish Resources Research Center 2023).

Furthermore, the Avian Research Center was established in 2007 and is the only one of its kind in the Kingdom of Saudi Arabia. Its primary focus is conducting research on various types of birds, including game birds, pet birds, and poultry. The center also aims to promote the production, genetics, and sustainability of rare bird species. Moreover, it actively supports the growth of the poultry industry in the country by providing training and consultancy services. It also develops relationships with other research centers, poultry companies, and bird breeders to advance the industry (Avian Research Center 2023).

Fourthly, the Camels Research Center was established in 1982. The center has collaborated with the Faculty of Veterinary Medicine and Animal Resources Departments to conduct research related to the fields of the center's activities that are concerned with camels. The Faculty of Veterinary Medicine places special attention on camels and encourages the conduct of several research projects on this subject due to the economic value of camels. Additionally, the center is linked to a small documentation library that has gathered information and documents related to camel research (Camels Research Center 2023). Fifthly, the Water Studies Center was established to conduct research on water resources, including their sources, quantity, quality, and their relationship to agriculture. The center also focuses on ecological issues. Its main function is to provide research, studies, and consulting programs in all areas of water and related fields (Water Studies Center 2023).

Additionally, the Faculty of Agriculture and Food Science (CAFS 2023a) encompasses numerous units that cover various disciplines. Firstly, the Extension Services Unit was established in 1997. It is a specialized unit that is supervised by a faculty member in the college. The unit collects agricultural research results and recommendations that have a practical impact on the needs of farmers and the development of agricultural production in Al-Ahsa Governorate. These results are then simplified, prepared, and printed as guidance leaflets or transparent slides, or recorded in educational videos. The purpose of these materials is to be used and distributed in order to achieve the college's goals. Additionally, the unit trains students in the methods and tools used in the courses. Secondly, the Plant Pests and Diseases Unit (CAFS 2023b) was established within the College of Agricultural and Food Sciences in 2011. Its main objective is to conduct scientific research and specialized studies related to plant protection. The unit focuses on accurately and quickly examining and diagnosing pests and diseases that have a negative impact on various agricultural crops. The unit also organizes scientific lectures, training programs, and specialized courses for agricultural engineers and those interested in the agricultural sector, particularly in the field of plant protection and diseases. It also provides scientific consultations to solve problems related to pests and plant diseases in a scientifically documented manner and offers necessary support to researchers, such as faculty members and students. Furthermore, the unit provides services to the agricultural sector in Saudi

Arabia, especially in the field of plant protection. Thirdly, the Bee Research Unit has been established at the College of Agricultural and Food Sciences and is linked to the University's Vice Presidency for Postgraduate Studies and Scientific Research. The unit plays a major role in developing and improving its services through applied scientific research. The research environment is equipped with the latest scientific technologies in the field of bees. The unit aims to involve the community by organizing seminars, educational workshops, and field visits. It is also responsible for producing and selling high-quality queens and providing education and training to the community through specialized workshops and training courses. Another objective of the unit is to organize field visits to serve farmers and beekeepers. Fourthly, the Environmental Protection Unit (EPU) was established in 2020 at King Faisal University with the approval of the Scientific Council. It is expected to collaborate with the Vice-dean of Postgraduate Studies and Scientific Research in the College of Agricultural and Food Sciences (KFU 2023b). The EPU has scientific teams assigned to address various environmental pollution issues, such as managing city waste, factories, and farms, controlling greenhouse gases, and reducing organic waste. The unit also focuses on preserving wildlife, biodiversity, and combating desertification. This includes contributing to efforts to reduce desertification and conducting studies on the biodiversity in the eastern region for its preservation.

3.2.2 Events Related to Food Security in CAFS

The CAFS is significant for achieving the KFU institutional Identity because of its focus on scientific studies and its unique location in Al-Ahsa Oasis, an important agricultural region in the Kingdom of Saudi Arabia. The college addresses challenges that arise in the agricultural environment and offers solutions based on sound scientific principles. Additionally, the faculty members provide guidance and expertise to individuals involved in agricultural activities. Throughout its existence, the college has offered more than a thousand courses, training and educational programs, and workshops in various agricultural disciplines. These include training courses for irrigation and drainage engineers, detecting cases of commercial fraud, beekeeping, managing greenhouses, propagating horticultural crops using tissue culture techniques, breeding flocks of sheep under the intensive system, regenerative breeding of pomegranate trees, and establishing fruit orchards.

Ever since its establishment, the CAFS has strived to organize numerous scientific meetings, with the most noteworthy ones being focused on the eminent product of the Al-Ahsa region, the date palm. These meetings and seminars attracted participants from all around the globe, thanks to their significance in the field of dates. Additionally, the college played host to various conferences, workshops, and symposiums renowned for their diverse and innovative nature. These included the First through Fifth Palm Symposium, the Meeting of Deans from Agriculture and Veterinary Medicine Colleges in GCC Countries, the First Symposium on Food Safety, the Agricultural Development and Water Resources Symposium, the Higher Agricultural Education Symposium and Future Requirements Conference, the World Conference on "Sustainability of Camel Production and Breeding," and the World Forum on the Impact of Covid-19 on Global Food Security: Actions and Measures.

The CAFS staff at education and research centers have provided numerous professional, technical, and practical consultations and studies for the community, individuals, and both governmental and private institutions. Some notable examples include:

- Analyzing soil and water samples for governmental and private agencies, as well as farmers.
- Assessing landslides in Al-Ahsa Governorate for Civil Defence. - Planning and designing the university's football stadium and overseeing its construction.
- Offering guidance on fertilizing lemon trees and identifying symptoms of iron deficiency for farms in Al-Ahsa.
- Implementing trotting fish to eliminate weeds in irrigation channels and drainage projects.
- Analyzing honey samples from various companies and citizens in the region.
- Examining dates samples for Al-Ahsa Development Company. - Contributing to the assessment of shrimp stocks in the Gulf on behalf of the State of Kuwait.
- Providing health guidelines for the university's swimming pool and irrigation water station. - Giving guidance on cultivating the Hasawi onion crop for the Ministry of Agriculture. - Offering statistical guidance and conducting data analysis for the Statistics Department at the Ministry of Agriculture in Al-Ahsa Governorate.
- Providing scientific guidance on palm service mechanization for farms in the region.
- Participating in the efforts of the national team at the National Authority for Wildlife Conservation and Development.
- Developing executive regulations for the marine scientific research system.
- Surveying shrimp fisheries in the waters of the Gulf Cooperation Council countries.
- Evaluating the current state of the marine environment in the Arabian Gulf.
- Assessing olive crop farms and determining appropriate methods based on their age.
- Conducting a comprehensive survey of demersal fish in the regional waters of the Gulf Cooperation Council countries.
- Analysing food groups and honey bee samples for individuals, private institutions, and companies to assess their quality.

Also, analyzing the quality of drinking water to determine its suitability for use in the governorate.

The College of Agricultural and Food Sciences (CAFS) had a significant impact on society, as well as its educational mission. Its employees played a pioneering role by providing specialized scientific consultations that helped solve many problems related to agricultural production. These problems included animal and poultry management, pest control, and food manufacturing. This activity benefited many agricultural institutions, companies, and government agencies in the region and the Kingdom of Saudi Arabia. CAFS was able to play such a vital and effective role because of its privileged location in Al-Ahsa Oasis. Its various departments were able to interact with the agricultural environment, raising awareness among farmers about crop production and processing. They also provided information about the breeding and production of animals and poultry. Since its establishment, CAFS has had a productive relationship with society, including individuals, institutions, and government agencies, through various activities and research. One of these activities is serving the community in different agricultural fields. They provide consultations to private farms in Al-Ahsa Governorate regarding plant productivity and soil issues. They also conduct soil analysis and water samples to determine their validity for agricultural production. Additionally, they design irrigation and drainage systems for new farms. Furthermore, CAFS contributes to information dissemination to farmers about controlling pests, insects, and plant diseases. They collaborate with environmental, water, and agriculture specialists in the region. The Plant Protection Department examines bee samples from government and private apiaries, diagnoses diseases, and provides necessary consultations to combat insects. CAFS also analyzes feed samples and creates diets required for animal and poultry production. They provide technical advice for animal production and the development of aquatic resources. The Department of Lands and Water holds training activities for irrigation and drainage engineers, as well as the Directorate of Agriculture and Water, concerning the use of computers and scientific devices for analyzing soil, water, and plant samples. The specialists in the Department of Home Economics carry out consulting missions and field visits to women's associations, nurseries, kindergartens, and hospitals in Al-Ahsa Governorate. Overall, CAFS focuses on its counselling efforts through field visits, public lectures and seminars, studies, consultations, and professional and technical studies.

The College of Agriculture and Food Sciences (CAFS) has participated in a committee to investigate and study pollution in certain areas of the Red Sea waters and its impact on consumers. Additionally, they have contributed to the preparation of a special report on the current state of the marine environment in the Arabian Gulf. CAFS has provided consultation and coordination meetings between the Department of Water Resources Development and the Agency of the Ministry of Agriculture for Fisheries Affairs. They have also discussed Saudi Arabia's experience with seawater farming, the concept of integrated pest management, and methods to prevent fungal diseases affecting palm trees. Furthermore, they have discussed the most important groups of pesticides used to control palm pests and their effects. They have also identified the causes of tree diseases leading to the death of planted trees on the road to King Fahd International Airport in Dammam. Additionally, CAFS has emphasized the significance and benefits of trees and offered consultations to the National Authority for the Protection and Development of the Wildlife Environment. They have also provided technical advice to the General Authority for Food Products, organizations interested in food safety, citizens, and officials. Moreover, they have provided technical advice on food standards to the Saudi Arabian Organization for Standardization and Metrology. In the Al-Ahsa Governorate, CAFS has provided technical advice to several automated bakeries to improve the quality of their products. Furthermore, they have provided essential consultations to help farmers in the region treat field crop problems. They have also offered economic and extension advice to the Ministry of Environment, Water, and Agriculture. Lastly, they have provided consultations on feasibility studies.

The College of Agriculture and Food Science (CAFS) contributed to community service by presenting general and specialized lectures, seminars, and panel discussions both within and outside of the college. These activities covered various agricultural disciplines and were represented by a wide range of topics. Some examples include: the use of grass carp fish to control aquatic weeds in the drainage channels of Al-Ahsa, the distinction between sea and land environments, the significance of maintaining clean beaches, modern techniques for feeding broiler chickens, the utilization of herbarium units, mathematical methods for estimating fertilizer requirements, agricultural machinery and forage collection, the control of garden pests, global environmental issues and pollution, the utilization of ornamental plants for medicinal and aromatic purposes, reproduction in flocks of sheep under intensive systems, the scientific foundations of feeding laying hens, modern principles of raising laying hens, the Saudi experience of seawater farming, integrated pest management, fungal diseases affecting palm trees and methods to prevent them, the most important groups of pesticides used for controlling palm pests and their impact, examining and diagnosing issues in poultry farming, scientific foundations for the care and feeding of milk cows, food security, and food loss and waste.

3.3 College of Veterinary Medicine (CVM)

The College of Veterinary Medicine at KFU was established in 1975. It is the only college in the Arab Gulf region that provides professionally qualified veterinarians to the community. These veterinarians work in various fields of animal health. The College of Veterinary Medicine aims to adopt a new curriculum that meets global standards and enhances the college's role in serving the community. Additionally, the college seeks to achieve its vision of promoting research to address local societal issues. It also aims to foster scientific and research collaborations with numerous Arab and foreign universities, as well as private sector institutions. The college is divided into several departments, including Anatomy Biomedical Sciences, Pathology, Microbiology and Parasitology, Veterinary Public Health, and Animal Husbandry, and Clinical Studies (CVM 2023).

3.4 Selected Contributions and Participations of King Faisal University in Promoting Food Security

KFU has played a leading role in promoting education and research on food security. The university has facilitated numerous conferences, workshops, and lectures on this important topic, where experts from various disciplines have convened to exchange knowledge and perspectives. These events have played a crucial role in increasing awareness about the challenges that food security is facing. This includes issues regarding the production, distribution, and consumption of food. Additionally, the events have explored possible solutions to these challenges, such as utilizing new technologies, implementing sustainable farming practices, and intervening with policies. The conferences, workshops, and lectures have attracted a diverse range of participants. This includes academics, policymakers, farmers, and students. Reputable speakers and experts in the field of food security have also been featured, sharing their knowledge and expertise with the attendees. These events have not only provided a learning platform and allowed for the sharing of knowledge, but they have also encouraged collaboration and networking among participants. This has created opportunities for like-minded individuals and organizations to connect, resulting in the establishment of new partnerships and initiatives. In subsequent Below are a few notable examples of KFU's contributions and involvement in promoting food security.

3.4.1 International Conference on Food Security and Environmental Sustainability

The first conference on food security and environmental sustainability organized by KFU held in Saudi Arabia, in KFU is seen as an important step towards achieving food security in the country. The conference aimed to promote sustainable practices in agriculture and food production, which can help ensure a consistent food supply for the population in the long term. One key impact of the conference was raising awareness about the significance of sustainable agriculture and its role in achieving food security. Policymakers, experts, and stakeholders from different fields came together to discuss and share ideas on how to ensure sustainable food production and reduce food waste. This exchange of ideas can lead to the development of effective policies and strategies for achieving food security in Saudi Arabia. Another important outcome of the conference was the emphasis on using modern agricultural technologies, such as precision farming, hydroponics, and vertical farming. These technologies can enhance food production efficiency, reduce water usage, and minimize the need for pesticides and fertilizers, thereby benefiting the environment and human health. Additionally, the conference emphasized the importance of international cooperation in achieving food security. Saudi Arabia heavily relies on food imports, so maintaining a stable global food supply chain is critical for the country's food security. The conference provided a platform for international cooperation and collaboration (KFU 2022).

The conference is organized in cooperation with the university's strategic partners, which include the Ministry of Environment, Water and Agriculture (MEWA) and the Arab League Educational, Cultural, and Scientific Organization (ALECSA). The conference focuses on themes related to the university's institutional identity and aims to contribute to achieving food security and environmental sustainability. The conference highlights the current situation of food security at the national and Arab region levels, discussing its challenges and how to overcome them. It also aims to build future strategies and policies that contribute to its improvement and environmental sustainability. The conference objectives include: contributing to the goals of natural initiatives such as "Green Saudi" and "Green Middle East", enhancing awareness of the importance of food safety, reducing loss and waste in a way that contributes to economic development, enhancing environmental sustainability in marine life and coastal ecosystems, learning from successful international experiences, assisting decision-makers in tackling food security challenges, coordinating efforts to strengthen national strategies, involving the private sector and local/regional/international organizations, preserving biodiversity, and promoting regional and international cooperation to prevent the entry of invasive species and reduce risks of pollutants and high-risk wastes. The conference consists of six main topics. Firstly, there is an insight into food security and environmental sustainability, discussing important concepts, contributions of agricultural production and systems, strategies for achieving food security, and national/regional/international experiences. Secondly, sustainable solutions for ecosystem protection are covered, including issues such as land degradation, desertification, biodiversity loss, habitat degradation, protection techniques (e.g., tree planting, regulating grazing), and the interrelationship between biodiversity, human health, and food security. Thirdly, "Food of the Future: Technologies and Innovation" explores achieving food security through domestic production, global market, and food aid. It addresses risks such as excessive dependence on food imports and discusses the use of modern technologies in smart agriculture, manufacturing technology in food quality and safety, and monitoring techniques for safe food. Fourthly, sustainability in the marine and coastal environment is discussed, focusing on solutions for managing these areas sustainably, coastal resource management, pollution prevention, establishment and maintenance of marine reserves, and the importance of the marine and coastal environment in achieving food security. Fifthly, the conference tackles the topic of hazardous environmental pollutants, treatment, and risk control. This includes mechanisms for the treatment, storage, transportation, and disposal of hazardous pollutants, the risks they pose to biodiversity, food security, and food safety, and their adverse effects on human and animal health. Additionally, the conference addresses the dimensions of food loss and waste at regional and international levels, considering causes such as the increasing demand for food, modern technologies in the food supply chain, governance of food subsidies, post-harvest treatments, and the social, cultural, economic, and environmental impacts of food waste. Overall, the conference aims to bring together experts and stakeholders to discuss these important topics and work towards solutions for achieving food security and environmental sustainability.

The conference has numerous and diverse sessions that cover various aspects of food security. These sessions include discussions on food security and environmental sustainability. They address issues, visions, and perspectives related to food security contributions, challenges, and opportunities. They also explore strategies for environmental sustainability. The second session of the conference focused on sustainable solutions for ecosystem protection. It discussed topics such as the vegetation cover in Saudi Arabia and the role of environmental reform in reducing desertification. Additionally, it addressed the contribution of soil health to environmental sustainability and food security. Best practices for biodiversity conservation were also discussed, along with challenges and potential solutions. Furthermore, the conference addresses issues related to future food, particularly in terms of technologies and innovations. This includes discussions on the role of modern technologies in the food production chain, with a focus on safety and quality. The role of technology and innovation in future food manufacturing is also examined, as well as the utilization of technology in national strategies for food security. Additionally, there are discussions on hazardous environmental pollutants and their treatment and control. These discussions cover topics such as achieving sustainability and biodiversity conservation in marine environments, scientific contributions to marine sustainability, marine pollution issues and solutions, types of organic waste and their treatment and reduction, waste management governance and sustainability, the role of environmental sustainability in development, and international regulations to reduce pesticide risks. Moreover, the conference addresses the issue of food loss and waste and its regional and international effects. This includes discussions on food security during the corona pandemic in the Arab world and the world at large, along with potential solutions. The use of artificial intelligence to achieve food security is also explored, as well as opportunities and challenges in developing sustainable and healthy nutritional systems (KFU 2022a).

The conference is accompanied by several scientific workshops that align with the topics and themes of the conference. These workshops were presented by specialists in the respective fields. The goals of these workshops are as follows: 1. Practices and governance options and their impact on food safety: Identify options for long-term food security and food safety. - Understand the contribution of management systems and tracking practices to food safety and environmental sustainability. - Learn good practices in managing hazardous organic pollutants and reducing their effects on food safety. - Explore the food safety approach based on the Saudi experience as a model. 2. Modern technologies in food security (present and future): - Examine the role of modern technologies in storage, distribution, and post-harvest transactions to reduce waste. - Analyze the role of manufacturing technology in accessing healthy food. - Discuss the future of digital agriculture to increase output and achieve food security. Additionally, the workshops will address the following issues related to environmental protection: 1. Stopping desertification and conservation of biodiversity techniques and solutions: - Protect the environment from sand creeping. - Promote the conservation of biodiversity in both plant and animal sectors. - Increase the number of green spaces planted with local environmental plants. - Work towards establishing land and natural reserves. - Focus on environmentally sustainable waste management, including recycling. 2. Reality and hope in environmentally sustainable waste management: - Raise awareness about the nature of waste and its environmental impacts. - Promote community awareness of waste sorting and recycling approaches to minimize harmful effects. - Encourage investment in plant waste manufacturing to add relative value. - Emphasize the importance of investment in solid and industrial waste management and recycling.

The conference is accompanied by a scientific exhibition that showcases the university's most prominent research projects, achievements, and scientific studies in the fields of food security and environmental sustainability. Some of the selected research and studies include a defect detection system for date crops using artificial intelligence, the analysis of nutrient components and antioxidant activity in hassawi rice, the investigation of food gap and food security in poultry meat in Saudi Arabia, the examination of the impact of macroeconomic variables on food security through a case study of red meat, the study of bacterial bio-fertilizers and their role in promoting plant growth, the enhancement of food wraps with plant extracts to extend the shelf life of a chilled chicken, the utilization of camel's milk to produce yogurt and soft cheese, the estimation of kinetic cross-sectional models to analyze the food security of cereal crops in Saudi Arabia, the balancing of toxic effects of wastewater on barley plant cells, and the utilization of date residues as natural nutrients for hydroponic plant cultivation as an alternative to fodder. In addition, the conference includes a Food Security and Environmental Sustainability hackathon, bringing together innovators, developers, and experts in the field. The hackathon aims to create digital solutions, applications, and technologies that contribute to a better future for food security and environmental sustainability. It is organized into different tracks, which include environmental protection and pollution reduction, waste management and recycling, rationalizing energy use, meteorology and climate change, water and food sustainability, and wildlife protection.

In conclusion, the inaugural food security and environmental sustainability conference in Saudi Arabia can be regarded as a noteworthy effort in attaining food security within the country. The conference advocated for sustainable agricultural practices, stressed the utilization of modern technologies, and underscored the significance of international collaboration in securing a reliable food supply chain.

3.4.2 Events Related to Food Security at KFU

Workshops, seminars, and lectures are events that occur at KFU. These events have been beneficial in enhancing the abilities of researchers, policymakers, and practitioners who are involved in addressing food security concerns. Participants have acquired valuable knowledge and skills through these training workshops, seminars, and lectures, which can be applied in their respective work to enhance food security in the region. For instance:

The College of Engineering organized and launched the inaugural engineering day exhibition for food security and environmental sustainability in 2023. The importance of this exhibition has show showcases the college's commitment to addressing the challenges of food security and environmental sustainability through an engineering lens. This is aligned with the university's identity surrounding food security and environmental sustainability, as well as its efforts to build and strengthen partnerships with relevant authorities, foster fruitful discussions and idea exchanges, and provide valuable recommendations. (KFU 2023).

The MEWA inaugurated the first international virtual workshop held by the Ministry on "The Future of Vertical Agriculture in the Kingdom". This workshop is part of the Ministry's efforts to localize and adopt modern agricultural technologies. The President of King Faisal University participated in the workshop along with a group of esteemed local and international scientists specializing in vertical farming, as well as leading Saudi and international companies in this field. Vertical farming techniques are crucial for agricultural development and water conservation. The government has allocated 100 million riyals for this purpose, and the procedures for obtaining licenses have been organized and streamlined. The workshop highlighted the importance of producing high-quality food that is free from pesticide residues and pollutants while keeping up with global population growth. The participants of the workshop recommended empowering investors and farmers with the necessary resources, such as water, energy, and land, for vertical farming. They also emphasized the need to develop policies and laws that promote vertical farming and facilitate approval procedures. Furthermore, research and development in this field should be encouraged through technical and financial support, and the capacities and knowledge of investors and farmers should be strengthened. It is worth mentioning that the global market size for vertical farming was estimated to be $3.16 billion in 2018. It is expected to experience significant growth, reaching $22.1 billion in 2026, with a compound growth rate estimated at 27.77% between 2018 and 2026 (Ministry of Environment, Water and Agriculture 2021a).

The College of Agricultural and Food Sciences at KFU held a lecture on September 18, 2019 titled "Food Security and Environmental Sustainability". The lecture focused on the progress made in plant genetics and how the agricultural industry can adjust to unfavorable environmental conditions such as climate change. It was emphasized that developing new genetic patterns in plants is one of the main ways to adapt agriculture in these circumstances. Furthermore, plants may need to be adaptable to different climates or assist in the migration of agriculture to new regions. Specific genotypes may be essential for optimal performance in areas modified for protected cultivation (KFU 2019a).

During the first institutional identity week of KFU, a lecture titled "Food Security Strategy in the Kingdom of Saudi Arabia" was delivered in 2020. The lecture was presented by the supervisor in charge of the implementation of the food security strategy at the General Grains Corporation. The supervisor discussed several important aspects that the corporation considers when implementing its strategy. Additionally, he explained the corporation's goals, which include creating a sustainable local food production system for products with unique advantages, achieving diversity and stability in external food sources, ensuring access to safe and prepared food in the Kingdom, and promoting healthy and balanced eating habits (KFU 2020a).

KFU has a collaboration with the National Nutrition Committee of the Food and Drug Authority. For instance during a visit by representatives from the National Nutrition Committee of the Food and Drug General Authority, the University president explained that the university had adopted a new institutional identity "Food Security and Environmental Sustainability" in response to the urgent need for research and studies on food security. The team from the National Nutrition Committee outlined their main tasks, which include evaluating the nutritional status of Saudi society, prioritizing interventions through the creation or revision of nutrition policies, establishing reference values for nutritional elements and updating them regularly, analyzing the nutrient content of food, offering recommendations and opinions on nutrition-related scientific studies to relevant authorities, conducting research and studies on nutrition, and establishing a national scientific research database in the field (KFU 2019b).

A workshop focusing on sustainable supply chains and their significance in attaining food security during times of crisis was organized in 2020, by the University Identity Management Committee in the departments for female students implemented an educational program called "Supply Chains and their Importance in Achieving Food Security during Crisis". The program aimed to highlight the significance of sustainability in food chains and its role in achieving food security. Moreover, it discussed the importance of sustainability in food supply chains and examined the challenges faced by global supply chains during the Corona crisis. The committee aimed to raise awareness about the institutional identity system at the departmental level for female students (KFU 2020c).

4 Collaboration Between Agricultural Academic Institutions and Government Bodies

To effectively develop and implement agricultural policies and programs for the purpose of achieving food security, it is imperative to establish collaboration between government agencies and agricultural academic institutions. This collaboration will provide access to expertise, research, training, education, and promote awareness. By working hand in hand with academic institutions, governments can foster a more sustainable and resilient agricultural sector that contributes significantly to attaining Saudi Arabia's food security objectives.

The country is facing severe weather conditions and a scarcity of water resources, which are significant challenges to food production. In the late 1970s, the government implemented programs and extracted groundwater, resulting in increased local production of cereal, fruit, and vegetable crops. However, these policies and programs were later reversed in the 2000s due to a rapid decline in water supplies (KAUST 2022). As a result, KSA now relies more on food imports, making its food security situation sensitive to disruptions in the global food market. In order to overcome these challenges, KSA has implemented important strategies and plans that combine farming practices with advanced technology in the animal industry. It has developed various programs as part of its five-year strategy for food security, including promoting a sustainable local food industry system, improving productivity, adopting sustainable practices, developing rural farming, and reducing food loss and waste. To achieve food security, KSA is taking steps to reduce food waste by changing the prevailing attitude of preparing excessive amounts of food and discarding leftovers (Ministry of Environment, Water and Agriculture 2021b). Since agriculture is an important economic sector in Saudi Arabia, the strength of society relies on its ability to produce food independently. Therefore, addressing agricultural issues requires raising awareness among growers about new agricultural technologies, increasing productivity through agricultural extension services, and reducing environmental impacts through research and educational programs at universities (Abunasser et al. 2022). Collaboration between agricultural institutions and development stakeholders also plays a crucial role in addressing development challenges and achieving sustainable collaboration (Fiaz et al. 2018). A recent study examined the characteristics of partnerships between agricultural cooperatives and other actors in KSA from 2016 to 2020. The results showed that cooperatives provided equipment, farming inputs, capacity building, and training to their stakeholders. The public sector was the main actor in inter-sector partnerships with agricultural cooperatives. More than half of the collaborations were classified as "strategic partnerships," providing valuable insights for policymakers on how agricultural organizations worked with other actors (Alotaibi and Kassem 2022).

5 King Faisal University Initiative "Stop Food Loss and Waste"

According to the World Food and Agriculture Organization, food loss and waste is an inefficient use of human resources, water, energy, land, and other natural resources that were used in its production. Food loss refers to any food that is lost in the supply chain between the producer and the market. This can occur due to insect infestations, harvesting problems, handling, storage, packaging, or transportation. Inadequate infrastructure, markets, price mechanisms, or the lack of legal frameworks contribute to the underlying causes of food loss. On the other hand, food waste occurs at the end of the food chain, specifically at the level of retail trade and final consumption. A recent study found that the Kingdom of Saudi Arabia has the highest rate of food loss and waste in the world. Annually, over 8 million tons of food suitable for consumption are wasted along the food supply chain, resulting in a loss of about 13 billion USD. To combat this issue, the Kingdom has launched initiatives entitled National Program for Reducing Food Loss and Waste. In the academic sector, KFU aims to achieve an advanced position in achieving food security. Their research and expertise focus on water, environment, agriculture, energy, health, technology, transportation, storage, management, and manufacturing. Moreover, the university has initiated an initiative called "Stop Food Loss and Waste" to reduce food loss and waste in the Kingdom as KFU establish itself as a leader in food security and environmental sustainability. By implementing this initiative and fulfilling its role in raising societal awareness of food loss and waste, it will contribute to achieving the goals of the Kingdom of Saudi Arabia. These goals include effectively investing in natural resources, enhancing operational efficiency, and ultimately improving food security. This initiative aims to educate, train, and qualify all sectors of society and stakeholders in both governmental and private institutions, as well as civil society, to work on reducing food loss and waste. The ultimate objective is to identify the most effective ways of reducing food loss and waste throughout the entire food supply chain, from the producer to the final consumer (Ahmed and Elbushra 2019).

According to the founders of the initiative (Ahmed and Elbushra 2019), the methods of implementing this initiative include providing lectures, training courses, and workshops to teach people how to reduce food waste and loss at different stages of the food supply chain in Saudi Arabia. Additionally, they plan to distribute informational pamphlets on ways to reduce food waste and loss, and raise awareness among all segments of society by creating audio-visual programs, utilizing social media, and creating applications. The initiative aims to benefit various groups such as employees of the Ministry of Education (including university and school students), faculty members at King Faisal University, and trainers in the schools of the Education Department in Al-Ahsa Governorate. Other stakeholders along the food supply chain, including producers and those involved in handling, storage, processing, distribution, and consumption, are also considered beneficiaries. In order to carry out this initiative and help achieve its objectives, all parties who are interested in preserving food and reducing food loss and waste will contribute. These parties include the following: agricultural extension workers in Saudi Arabia, nutrition officials in governmental institutions (such as schools, kindergartens, hospitals, and prisons), charitable societies and associations dedicated to preserving food, Imams of mosques who play a role in memorizing the Qur'an, providers of food services in restaurants and hotels, as well as all members of the community in public places and shopping areas. Additionally, the University Center for Communication and Media and the Department of Communication and Media within the Faculty of Arts are also involved in the initiative.

6 Contribution of Agricultural Research in Enhancing Food Security

Agricultural research plays a crucial role in improving food security in developing nations. Increasing agricultural research can have a significant impact on global food availability and accessibility. Universities, research institutions, and centers are important contributors to research, leading to the creation of knowledge. Universities, in particular, are recognized as sources of academic knowledge, which has led to the establishment of scientific research chairs as a strategic component in the development and implementation of research. Agricultural technologies and research have a significant worldwide impact on food security. Saudi Arabia, with its numerous agricultural colleges and research centers, is well-equipped to enhance food security by considering the four dimensions identified by the Economic and Social Council (2017)n: food availability, accessibility, utilization, and stability. According to Abunasser et al. (2022), universities in Saudi Arabia play a critical role in sustaining food security through education, regulations, policies, scientific research, and community partnerships. The Food and Agriculture Organization (FAO) defines food security as the physical, social, and economic access to safe and nutritious food that meets individuals' dietary requirements and preferences for an active and healthy life (Economic and Social Council 2017). The existence and sustainability of food security are dependent on the amount and type of capital, both human and financial, needed to support and implement research outcomes in the form of knowledge or physical products. The relationship between technologies and the pillars of food security is significant. New technologies aim to increase agricultural productivity, improve soil fertility, increase water availability, and combat abiotic stresses, thus impacting the availability of food. Innovations in storage, transportation, refrigeration, and agro-processing contribute to the accessibility of food. The science of producing crops with high nutrient value plays a role in the utilization and consumption of food to prevent malnutrition. Lastly, the food stability pillar focuses on using science, technology, and innovation (STI) to adapt to and mitigate the effects of climate change (Abunasser et al. 2022).

7 Scientific Chairs in KSA

Fundraising and research management have recently been developed in Saudi Arabia, where many universities have initiated a number of research chairs that lead research and innovation in various aspects related to their specializations (Al-Thaqafi 2021). These research chairs are created through partnerships between academic universities and other organizations, with the collaboration developed through joint efforts. Academic centers take the lead in scientific endeavors, while partners provide financial support, primarily from the private sector. The purpose of this partnership is to generate scientific knowledge and benefit communities. The significance of these chairs lies in the amalgamation of qualities that can cater to the needs of both parties involved. Moreover, this collaboration is crucial for social and cultural development at the community level, as it brings together expertise and qualifications to collaborate on knowledge generation and problem-solving. Priority is given to issues related to agriculture and food security in modern communities, thus the research and inventions also focus on the needs of agricultural and food activities, among others. Table 2 presents a list of some Saudi universities hosting research chairs in agriculture and the

Table 2 Research chairs focused on agriculture and food security at universities in Saudi Arabia

University	Total number of chairs	The number of chairs related to agriculture and food security
King Saud University	27 Scientific chairs	9
King Faisal university	10	4
King Abdulaziz University	22 chairs 5 complete 4 non-complete	5
Hail University*	10	1
Najran University*	1	NA
Princess Nourah bint Abdulrahman University	15	2
King Abdullah University for Science and Technology		
King Khalid University	1	
Qassim University	5	1

Source Universities websites. KSU (2023a), KAU (2023), KFU (2023a), KAUST (2015), PNU (2023), Qassim University (2023), Northern Border University (2023), KACST (2020), KKCSR (2023), The Custodian of The Two Holy Mosques Institute For Hajj And Umrah Research (2023)

number of chairs they have. The information has been gathered from the websites of Saudi universities, as well as a compilation by certain institutions and reports addressing these matters. The activities of these chairs encompass food security, plants, foods, livestock, environment, sustainability, and other relevant subjects.

7.1 ALBilad Bank Chair for Food Security (ABCFS) in Saudi Arabia

Albilad Bank Chair for Food Security (ABCFS) in the Kingdom of Saudi Arabia is a scientific chair that specializes in the area of food security. Its aim is to address the current and future food security challenges that the Kingdom of Saudi Arabia faces. The founder and presenter of this chair proposal is Adam Elhag Ahmed, who is a faculty member in the Department of Agribusiness and Consumer Sciences at the College of Agricultural and Food Sciences (Bank Albilad 2022). Presently, the chair is under the management and supervision of the Deanship of Scientific Research at the Vice Presidency for Postgraduate Studies and Scientific Research at KFU. The idea of the chair was devoted to achieving the pioneering role of KFU in community service. Its purpose is to achieve the university's identity, enrich scientific research, and qualify national cadres to contribute to achieving sustainable development in accordance with the Kingdom's Vision 2030. The importance of the chair is illustrated by its ability to train and qualify a highly-skilled national cadre that can effectively contribute to preparing, implementing, and evaluating food security strategies. Additionally, the chair aims to spread food awareness, strengthen national capabilities, provide specialized advisory bodies, create an effective community partnership, and propose the establishment of a system to provide exploration and early warnings of food security challenges in the Kingdom of Saudi Arabia. The chair aims to achieve specific goals, such as studying the current and future challenges related to food security, determining the factors and difficulties that may hinder the achievement of food security, conducting scientific research to determine the size of the food gap in the strategic agricultural products, providing advisory services, holding panel discussions, workshops, conferences, and training courses related to food security, working to activate joint cooperation between institutions and agencies related to food, and contributing to Bank Albilad's social responsibility to achieve food security. The ABCFS was funded by Bank Albilad with a financing of 5 million Saudi riyals distributed over five years. Statistics regarding the achievements of the first stage of ABCFS include the following:

(a) The establishment of a clinic named "Nutrition Awareness and Education Clinic"
(b) Representation and participation in various international conferences
(c) International collaboration with a prestigious international university
(d) Conducting a television interview for a news channel.
(e) Writing 13 journalistic articles for both international and national newspapers, including publications such as "Al-Youm," "Al-Riyadh," and "Al-Bilad," all attributed to the chair.
(f) Participation in six international conferences.
(g) Obtaining a patent registration.
(h) Development of a prototype.
(i) Implementation of a rehabilitation program.
(j) Conducting an awareness campaign.
(k) Development of a marketable product.
(l) Publishing 41 research papers in reputable international journals under the name of Chair, as well as contributing a chapter to a book published by a prestigious publishing house.
(m) The research involved collaborations with several non-Arab countries such as China, Japan, Malaysia, Pakistan, India, and Italy, as well as collaborations with Arab countries like the United Arab Emirates and Egypt.

The accomplishments of the ABCFS in the first phase are related to the Kingdom Vision 2030, the Ministry of Education Vision, and KFU's institutional identity. These connections exist in various fields such as agriculture, health, nanotechnology, industry, artificial intelligence, management, environmental and agricultural sustainability, information, and communication technology. The details of these areas were depicted in the following sections.

1. Link Between ABCFS Achievements and Kingdom Vision 2030

1.1 Field of Agriculture

(a) Utilizing environmentally friendly natural preservatives to reduce post-harvest losses and waste, thus promoting sustainable food security.
(b) Providing environmentally friendly biological control agents as alternatives to harmful pesticides.
(c) Recycling agricultural waste into concrete to compensate for the lack of natural resources, leading to a reduction in greenhouse gas emissions and the preservation of natural resources.
(d) Analyzing the problem of food loss and its threat to food security and sustainability in the Kingdom of Saudi Arabia.
(e) Enhancing the production and quality of the active substances in the amaranth plant in sandy lands by utilizing environmentally friendly materials.
(f) Isolating environmentally friendly bacteria from the soil and utilizing them as biofertilizers to improve soil fertility and plant productivity.
(g) Using palm residues and seeds as building materials for sustainable waste management.
(h) Utilizing biofertilizers such as blue-green algae that fix nitrogen and are compatible with the local environment.
(i) Enhancing the quality of the shrimp breeding system and implementing its use in isolated desert areas within the Kingdom.
(j) Achieving food security and providing fish and fish products.

1.2 Field of public health

(a) Improve overall health by creating effective treatments for individuals suffering from diabetes.
(b) Contribute to the national economy by producing pharmaceutical products that include dabigatran.

1.3 Field of nanotechnology, industry, and artificial intelligence,

a. The development of innovative methods and nanomaterials for treating industrial wastewater in textile factories.
b. The production of nanofibers to enhance food security, such as creating films for packaging and preserving agricultural crops (fruits and vegetables). These nanofiber films also offer protection against bacterial damage.
c. The manufacturing of zinc nanoparticles using papaya leaves. These nanoparticles can decompose organic pollutants and pathogens, serving as an antioxidant to improve food security and overall health. \
d. The production of sensors for various applications, including water and food monitoring.
e. The advancement of gas sensing technology, specifically for monitoring agricultural and processed foods. This technology aims to safeguard citizens' health.
f. The utilization of nanotechnologies in pharmaceutical manufacturing.

g. The application of renewable, non-polluting solar energy for water purification. 8. The preparation of nanomaterials to be used in water purification.
h. The creation of flexible and robust automated decision-making systems for product evaluation. This is particularly important in the food industry, as the need for total quality management continues to grow.

2 Link Between ABCFS Achievements and Ministry of Education Vision

2.1 Environmental and agricultural sustainability

The research achievements of the first phase conducted by Bilad Bank align with the Ministry's goals in terms of environmental and agricultural sustainability. These achievements include:

(a) Achieving control over apple bacterial pathogens by utilizing environmentally friendly marjoram oil instead of chemicals;
(b) Using natural alternatives as additives in fish feed to minimize their negative impact on the environment and consumers, while also preventing the accumulation of these substances in fish tissues.
(c) Deploying green resources like cyanobacteria for biological control against plant microbes, thereby utilizing autotrophic resources that are environmentally friendly and promote sustainable growth at a reduced cost.
(d) Developing a sustainable method for preserving post-harvest vegetables for longer durations. This is accomplished by treating them with environmentally friendly compounds, which not only reduces waste but also ensures food security.
(e) Contributing to the development of bio-fluke technology for shrimp farming to achieve environmental and agricultural sustainability, utilizing environmentally friendly materials that act as catalysts to enhance plant productivity and quality across various soil types, aiming to improve plant growth.

2.2 Public health

In the field of public health, numerous research activities have been conducted to align with the goals of education. These research endeavors include enhancing the quality of food, water, and agriculture, resulting in a significant enhancement in human health. Furthermore, there has been progress in developing a therapeutic formula for individuals with elevated blood lipids. Additionally, through research, the pharmaceutical industry has explored the utilization of advanced technology and natural compounds to develop clinical procedures that aid patients with renal ischemic disease. Moreover, dabigatran, a medicine, directly ameliorates human health by treating fungal diseases and indirectly contributes by treating infected animals and producing safe and healthy food. Lastly, in the realm of health, efforts are being made to produce a therapeutic product for managing type 2 diabetes.

2.3 Fields of nanotechnology, industry, and information and communication technology

(a) Creating a secure environment for data and digital operations, developing, implementing, and overseeing the national cyber security strategy.
(b) Exploring environmentally friendly techniques for producing certain types of nano-fibers that can be used to protect agricultural crops from bacterial damage.
(c) Utilizing biocompatible, biodegradable, and non-toxic nanofibers in treating wounds to prevent bacterial infections and speed up the healing process.
(d) Incorporating agricultural waste into the cement and concrete industry to promote environmental conservation and meet social and economic needs.
(e) Treating wastewater and reusing it in industrial or agricultural settings.
(f) Removing dyes from water using ultraviolet rays through photocatalytic processes, as an example of addressing industrial pollution.
(g) Producing bio-charcoal from palm fronds and date seeds as a sustainable alternative to cement, enhancing the performance of concrete.
(h) Using agricultural residues in concrete production to reduce carbon emissions and promote sustainable infrastructure development.
(i) Applying gas sensing technology to indirectly monitor the excessive use of fertilizers in agriculture.

3 Link between ABCFS Achievements and King Faisal University identity

3.1 Field of Agriculture:

(a) The use of marjoram oil as a preservative in apple fruits. This oil is environmentally friendly, low-cost, natural, and effectively eliminates pathogenic bacteria.
(b) Improvement of fish hatcheries' productivity through enhancing fish reproductive efficiency. This leads to increased production of young fish, which allows for the expansion of fish production.
(c) Provision of environmentally friendly plant antimicrobials that serve as a substitute for harmful pesticides.
(d) Development of a sustainable method to preserve the vitality of vegetables, including extending their harvesting period. This is achieved by treating them with environmentally friendly natural compounds, reducing wastage and maintaining food security and environmental sustainability.
(e) Isolation of environmentally friendly bacteria from the soil of Al-Ahsa. These bacteria reduce the need for chemical fertilizers, which cause significant environmental harm. They can be used as biofertilizers to enhance soil fertility and plant productivity.

3.2 Fields of nanotechnology, industry, management, and information and communication technology?

(a) They have successfully used prepared nanoparticles to efficiently remove pollutants and pathogens from wastewater.

(b) They have conducted a study on gas sensing technology, which is closely connected to environmental and air quality control in manufacturing processes.
(c) They have developed solar energy techniques using photocatalysis to treat industrial wastewater contaminated with textile dyes.
(d) They have utilized nano-fibers as wrapping films for agricultural crops to shield them from bacterial damage and to safeguard public health.
(e) By utilizing agricultural waste in construction, they are able to reduce waste and minimize the environmental impact of the cement and concrete industry.
(f) Using sensors, they can detect volatile organic compounds that harm or spoil fruits and meat, making them applicable in food science research.
(g) They have analyzed web traffic to ensure the security of significant information regarding food security and environmental sustainability against global attacks.
(h) They are conducting research on consumer purchasing behavior and the causes of excessive buying habits to lessen the consequences of food waste.

3.3 Field of Public Health

(i) Nano-fibers made from chitosan extracted from shrimp peels are being utilized as dressings for wound healing.
(j) Researchers are focusing on the utilization of natural products found in the local environment to develop new treatments.
(k) Environmentally friendly silver nanoparticles are being used to treat oral fungal infections.
(l) There is a trend towards exploring the medical and clinical uses of natural plants specific to the Saudi environment.
(m) Dabigatran, a medication, shows potential in treating fungal diseases affecting humans.
(n) Animal fungal diseases are being treated, and safe animal products are being produced based on experiments involving drug reuse.

7.2 Date Palm Research Chair

Once, dates were a staple food in the diet of people in Saudi Arabia. The Date Palm Unit conducts research to promote the cultivation of date palms through education, outreach, and scientific investigation. Research programs collaborate with related colleges, as well as national and international organizations, to address the challenges facing date palm agriculture. The Chair of Date Palm Research (CDPR) recently published a study titled "Genes Involved in Sex Pheromone Biosynthesis of Ephestia Cautella, an Important Pest in Food Storage, Determined by Transcriptome Sequencing.

7.3 Proposed Research Chairs

Several studies have been conducted on food security in Saudi Arabia. Faiz et al. (2018) proposed replacement experiments that could be carried out to expand local food production and promote food security, emphasizing the need for effective use of agricultural extension services. Alsubaie and Berekaa (2021) conducted a review of the current state of food safety in Saudi Arabia, identifying strengths, weaknesses, opportunities, and challenges in the food safety system and suggesting strategies to enhance it, such as high-quality education, research, and training programs. The study aimed to inform policymakers and encourage academic institutions to support food safety education and research. Hanbazaza and Mumena (2022) evaluated the food security of low-income women in Jeddah, identifying various strategies they employ to deal with food insecurity, which can negatively impact their overall health. The study called for further research to better understand the causes of food insecurity and its effect on disadvantaged groups in Saudi Arabia. Baig et al (2022) aimed to raise awareness of food waste and promote the implementation of remedial measures by policymakers and organizers. The study identified youth and women as key groups to target with awareness campaigns and behavioral change interventions. Al-khateeb et al. (2021) examined the significant economic, social, and environmental costs of food waste in Saudi Arabia, which comprises 33.1% of the total available food, and recommended improvements to cold chain storage facilities, as well as greater awareness and behavioural changes to reduce waste. Haque and Khan (2020) analyzed rainfall and temperature trends in Saudi Arabia from 1967 to 2016 and evaluated their impact on crop production. Their findings showed a significant increase in typical temperatures, mainly in the summer, which reduced crop yield, while rainfall had a positive effect on all crops.

8 Conclusion and Prospects

In Saudi Arabia, higher education institutions play a significant role in enhancing food security. They do so through various means, such as conducting scientific research to address the obstacles that hinder food security in the country. These institutions also focus on teaching and learning, ensuring that Saudi graduates are knowledgeable about the issues surrounding food security and the agricultural sector. The expertise of these graduates greatly contributes to achieving food security. Furthermore, higher education institutions forge partnerships with the community, actively collaborating with local organizations to identify key obstacles to food security and devise appropriate solutions. By aligning efforts with the community, these institutions aim to achieve sustainable food security in Saudi Arabia. To further enhance food security, greater efforts are needed to address the obstacles and advance modern agricultural technologies that bolster both the quantity and quality of food production while preserving the integrity of food systems.

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Index

A. E. Ahmed et al. (eds.), *Food and Nutrition Security in the Kingdom of Saudi Arabia, Vol. 1*, https://doi.org/10.1007/978-3-031-46716-5