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# Food and Nutrition Security in the Kingdom of Saudi Arabia, Vol. 2

## Macroeconomic Policy and Its Implication on Food and Nutrition Security

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*Editors*
Adam E. Ahmed
Department of Agribusiness and Consumer Sciences
College of Agricultural and Food Sciences
King Faisal University
Al-Ahsa, Saudi Arabia

Department of Agricultural Economics
Faculty of Agriculture
University of Khartoum
Khartoum, Sudan

Jameel M. Al-Khayri
Department of Agricultural Biotechnology
College of Agricultural and Food Sciences
King Faisal University
Al-Ahsa, Saudi Arabia

Azharia A. Elbushra
Department of Agribusiness and Consumer Sciences
College of Agricultural and Food Sciences
King Faisal University
Al-Ahsa, Saudi Arabia

Department of Agricultural Economics and Agribusiness
College of Agriculture
University of Bahri
Khartoum, Sudan

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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 two volumes of this monumental reference book and wish them continued success.

Dr. Mohammed Abdul Aziz Al-Ohali
President
King Faisal University
Al-Ahsa, Saudi Arabia

# 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

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# Editors and Contributors

## About the Editors

**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.

## Contributors

**Hayam S. Abdelkader** Department of Virus Research, Molecular Biology Lab, Plant Pathology Research Institute, Agriculture Research Center (ARC), Cairo, Egypt

**Hanady Mustafa Abdelradi** Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia;
Agricultural Economic Research Institute, Cairo, Egypt

**Adam E. Ahmed** Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia;
Department of Agricultural Economics, Faculty of Agriculture, University of Khartoum, Khartoum, Sudan

**Shamseddin Musa Ahmed** WMII, University of Gezira, Wad Madani, Sudan;
Visiting Researcher, Institute of Research and Consulting, King Faisal University, Al-Ahsa, Saudi Arabia

**Jameel M. Al-Khayri** Department of Agricultural Biotechnology, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia

**Muneera Q. Al-Mssallem** Department of Food and Nutritional Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia

**Rahmah N. Al-Qthanin** Department of Biology, College of Sciences, King Khalid University, Abha, Saudi Arabia;
Prince Sultan Bin-Abdul-Aziz Center for Environment and Tourism Studies and Researches, King Khalid University, Abha, Saudi Arabia

**Randah M. Al-Qurashi** Department of Food and Nutritional Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia

**Hayat Z. Al-Shalan** Department of Human Nutrition, College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia

**Ahlam Mohammed Alateeq** Department of Food and Nutritional Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia

**Salah Aleid** Department of Food and Nutritional Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia

**Fatima M. Alessa** Department of Food and Nutritional Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia

**Budour A. Alghamdi** National Research and Development Center for Sustainable Agriculture (Estidamah), Riyadh Techno Valley, King Saud University, Riyadh, Saudi Arabia

**Dina Omer Mohamed Ali** Department of Food and Nutritional Sciences, College of Agriculture and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia;
National Food Research Center, Khartoum, Sudan

**Abdulrahman M. Almadini** Department of Agricultural Environment and Natural Resources, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia

**Bashayer H. Almagthali** Department of Agricultural Biotechnology, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia

**Khadija I. Alnabbat** Department of Food and Nutritional Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia

**Modhi O. Alotaibi** Department of Biology, College of Sciences, Princess Nourah Bint Abdulrahman University, Riyadh, Saudi Arabia

**Nahaa M. Alotaibi** Department of Biology, College of Sciences, Princess Nourah Bint Abdulrahman University, Riyadh, Saudi Arabia

**Meshabbab A. AlQahtani** Independent Researcher, Khobar, Saudi Arabia

**Shahrah S. AlQahtani** Department of Environment and Sustainable Development, College of Science, University of Bahrain, Sakhir, Kingdom of Bahrain

**Heba Althawaini** Department Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia

**Fahad Alzahrani** Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia

**Ibrahim El-Dukheri** Arab Organization for Agricultural Development, Khartoum, Sudan

**Hamadttu Abdel Farag El-Shafie** Date Palm Research Center of Excellence, King Faisal University, Al-Ahsa, Saudi Arabia;
Department of Crop Protection, Faculty of Agriculture, University of Khartoum, Khartoum North, Shambat, Sudan

**Azharia A. Elbushra** Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, AL-Ahsa, Saudi Arabia;
Department of Agricultural Economics and Agribusiness, College of Agriculture, University of Bahri, Khartoum, Sudan

**Nagat Elmultham** Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al Ahsa, Saudi Arabia;
Department of Agricultural Economics, Faculty of Agricultural Sciences, University of Gezira, Wad Madani, Sudan

**Nagat Elmulthum** Department Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia;
Department of Agricultural Economics, Faculty of Agricultural Sciences, University of Gezira, Wad Madani, Sudan

**Mutasim Mekki Elrasheed** Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia

**Abda Abdalla Emam** Department Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia;
Department of Agricultural Economics, Faculty of Agricultural Studies, Sudan University of Science and Technology, Khartoum, Sudan

**Somaia Rogaime Jaffar** Department of Agricultural Economics and Agribusiness, College of Agriculture, University of Bahri, Khartoum, Sudan

**Ezzat Khan** Department of Chemistry, College of Science, University of Bahrain, Sakhir, Kingdom of Bahrain;
Department of Chemistry, University of Malakand, Chakdara, Lower Dir, Khyber Pakhtunkhwa, Pakistan

**Hattim Makki Mohamed Makki** Date Palm Research Center of Excellence, King Faisal University, Al-Ahsa, Saudi Arabia;
Department of Food Science and Technology, College of Agricultural Studies, Sudan University of Science and Technology, Khartoum, Sudan

**Abdalbasit Mariod** Biological Department, College of Science, University of Jeddah, Jeddah, Saudi Arabia;
Indigenous Knowledge and Heritage Centre, Ghibaish College of Science and Technology, Ghibaish, Sudan

**Maisa Bushra Omer** Department of Food and Nutritional Sciences, College of Agriculture and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia;
Department of Food Engineering and Technology, College of Engineering and Technology, University of Gezira, Wad Madani, Sudan

**Suzy Salama** Indigenous Knowledge and Heritage Centre, Ghibaish College of Science and Technology, Ghibaish, Sudan

**Muhammad N. Sattar** Central Laboratories, King Faisal University, Al-Ahsa, Saudi Arabia

**Haroon Elrasheid Tahir** School of Food and Biological Engineering, Jiangsu University, Zhenjiang, Jiangsu, China

**Imad Eldin Abdel Karim Yousif** Department of Agricultural Economics, College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia;
Department of Agricultural Economics, Faculty of Agriculture, University of Khartoum, Khartoum, Sudan

# 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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A. E. Ahmed (✉)
Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: ayassin@kfu.edu.sa; adamelhag2002@yahoo.com

Department of Agricultural Economics, Faculty of Agriculture, University of Khartoum, Khartoum, Sudan

 
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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 thousand $km^2$, 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 Factbook (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.

The three most populous regions in the Kingdom are Makkah Al-Mukarramah, Riyadh, and the Eastern region, with populations of 8.8 million, 8.5 million, and 5 million, respectively. Together, these regions account for more than two-thirds of the total population in Saudi Arabia (Table 2). The least populous region in the Kingdom is the northern border region, with a population of 0.375 billion people, representing approximately 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 Factbook 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 approximately 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 (Konema 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, b; Saud 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 expected to gradually fade in 2020,

**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, 2022) and Saudi Central Bank (2023)

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 less than 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 approximately 1623 metric tons in 2020. Despite a decrease in vegetable cultivation area from 99,000 ha in 2018 to 74,000 ha in 2020, there was an increase in vegetable production. This increase can mainly be attributed to an increase in productivity. However, during the same period, the area used for wheat and barley production declined. Wheat cultivation decreased from 95,000 ha in 2018

**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 (2023a, b)

**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), 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

to 87,000 ha 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 69%, 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 6% decrease in camel meat production in 2020. In total, sheep represented 59%, goats more than a third, camels 3%, and cows only 4% of the total livestock population of 16.05 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

**Table 9** Plant production area and productivity

| 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 |

Area: 1000 ha, yield: kg/haproduction: 1000 mt, trees: 1000

**Table 10** Saudi Arabia livestock, poultry, and fish production (animals and slaughtered animals:1000 heads, production:1000 mt, birds: million)

| | 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 |

*Source* Compiled by the author based on the data from Arab Organization for Agricultural Development (2022)

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 four-fold 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 to 2021

| 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 |

Quantity: Million MT, Value: Million USD, Area 1000 ha
*Source* Compiled by the author based on the data from Agricultural Statistics Bulletin (2023)

## 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 ten years with a two-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; ADF 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

| | 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 |

Amount of loan: million USD
*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 approximately 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 (approximately 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
# Food Prices and Food Security in Saudi Arabia: Facts and Trends

**Azharia A. Elbushra**

**Abstract** Price volatility has a significant impact on food security. Saudi Arabia relies on food imports to meet local demand due to water scarcity and unfavorable weather conditions restricting local production. Therefore, increasing food prices remain a major concern for Saudi Arabian food companies. This chapter focuses on analyzing food price changes in terms of facts and trends through the Consumer Price Index (CPI), a measure of inflation, and changes in the average prices of some food commodities. The results show that, the food price index in Saudi Arabia is greater than the general consumer price index during the period of January 2001 to June 2022. It also indicates that food and beverages exhibit the highest average score of CPI compared to the general index during the period of January–May 2023. In addition, the results also show that in 2022, Food and non-alcoholic scored the second ranking of the CPI components. Moreover, the results reveal that there is annual increase in average prices of some food items such as imported honey, coffee, red meat, local glass cheese and Fish. Thus this price increase in food prices will affect households' ability to access healthy and nutritious food, resulting in an increased prevalence of undernourishment. Therefore, a food security strategy focusing on increased agricultural efficiency, social protection and trade openness is recommended to ensure a sustainable and affordable food supply.

**Keywords** Average prices · Food groups · Food price volatility · General price index · Inflation

A. A. Elbushra (✉)
Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, AL-Ahsa 31982, Saudi Arabia
e-mail: aaali@kfu.edu.sa; azhbushra@yahoo.com

Department of Agricultural Economics and Agribusiness, College of Agriculture, University of Bahri, Khartoum, Sudan



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## 1 Introduction

Food prices play a significant role in food security at the household, national, and global levels. The international community is concerned about soaring food prices as it is considered a threat to global food security. When food prices increase, and incomes decrease, it affects the accessibility of healthy and nutritious food for households, resulting in increased undernourishment prevalence. According to The Food and Agriculture Organization of the United Nations (FAO 2011) price volatility has a strong impact on food security as it affects household incomes and purchasing power. It will also relate to price levels and impact welfare and food security. Higher prices will negatively affect consumer welfare, while it will have a positive effect on producers. In the same line Díaz-Bonilla (2016) stated that in the short-run, producers will gain, contrary to consumers from high food price, while in the medium to long rum, both will be benefited. Yamin et al. (2021) further stated that price increases, especially in food, are considered a source of increased poverty, particularly for consumers since it would increase household expenditure on food, given constant income. Mkhawani et al. (2016) revealed that in Runnymede Village, South Africa, soaring food price had a negative effect on female-headed poor households.

Soaring food prices would have an adverse effect on nutritious food, as declared by the FAO et al. (2022). Recently, the number of people worldwide who are unable to pay for a healthy diet increased by 112 million, reaching approximately 3.1 billion due to the impact of increasing consumer food prices during the COVID-19 pandemic. Ambachew et al. (2012) declared that the continuous increase and volatility of food prices are the top agenda of the international community. Developing countries are highly exposed to food insecurity as they lack the financial ability to afford basic food commodities.

The global economy faces numerous challenges, including high inflation rates in various countries and commodities. Worldwide, there are higher energy prices due to supply shortages. As a result, interest rates have increased to control inflation. Additionally, the war between Russia and Ukraine has exacerbated the debt situation, particularly in low-income countries that struggle with food insecurity (OECD 2022). Björn et al. (2022) have reported that there is a food crisis worldwide, as price shocks worsen food insecurity. Since 2018, conflict, climate change, and the COVID-19 pandemic have made the food insecurity situation even worse. Kalkuhl et al. (2016) explained that the recently most crucial determinants of agricultural markets include, energy prices, interest rates and monetary policy, financial investments and speculation, unexpected trade control, or absence of information. FAO experts have stated that the surge in food prices and variability will continue due to increased demand from population growth, scarcity of natural resources, biofuel price increases, and low agricultural productivity. They have also noted that this variability puts smallholder farmers and poor consumers at greater risk of poverty. Furthermore, while high prices in the short term will worsen food insecurity, in the long term, it can improve food security by increasing investment in the agriculture sector (FAO 2011). Brüntrupm (2008) has similarly suggested that the continuing food crisis can harm most urban and rural households in the short term, but it can have positive effects on poverty.

Inflation is a phenomenon whereby there is an overall increase in the price level of goods and services, resulting in a decrease in the purchasing power of consumers and producers over time, assuming all other factors remain constant (Snell 2022a). Consumer price index (CPI) inflation is a measure of the change in prices of a basket of goods and services that are typically purchased by specific groups of households (OECD 2023). The Consumer Price Index is considered the most widely used and comprehensive measure of inflation (Snell 2022b). Internationally, inflation levels remain high, prompting central banks to adopt tighter monetary policies. CPI inflation is expected to continue to increase, reaching 5.2% in 2023, before falling to 3.2% in 2024. However, inflationary pressures may persist, even with this decline (World Bank 2023a). This chapter aims to assess the facts and trends of food price variability in Saudi Arabia. The chapter covers the trend of the international food price, analysis of the variability of food prices in Saudi Arabia using Consumer Price Index (CPI) as a measure of inflation and changes in average prices of some food commodities in Saudi Arabia.

## 2 Analysis of International Food Price Variability

The global consumer price index, as well as general indices, has consistently increased from 2000 to 2022 at a rate of 2.8%, reaching its highest point in 2022 (Fig. 1). The rise in CPI from 2020 to 2022 is likely due to the Covid-19 pandemic and Russia's invasion of Ukraine.

International food prices have been increasing globally, which has had a negative impact on food security, reflecting on hunger, poverty, and balance of payments instability. The FAO (2023) defines the FAO Food Price Index (FFPI) as a measure

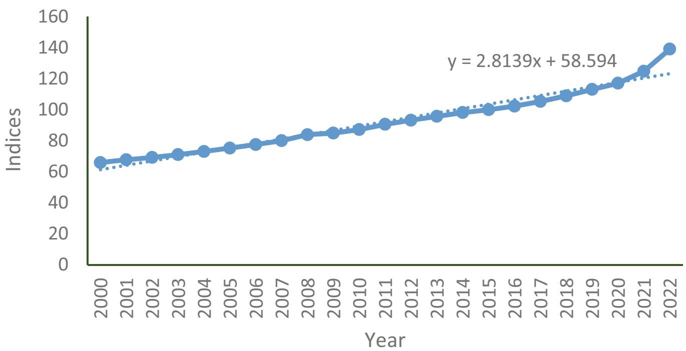


**Fig. 1** Performance of global consumer price index (2015 = 100) during the period 2000–June 2022. *Source* Prepared by the author based on data from FAOSTAT (2023)

of monthly changes in international prices for a basket of food commodities. It includes the average of five commodity group price indices, weighted by their average export shares between 2014 and 2016. The prices of agricultural commodities during the 2006–2008 witness commodity price boom, mainly due to unfavorable weather conditions and the use of some food commodities for biofuel production (Baffes and Haniotis 2010). Barua (2022) stated that prices have been consistently rising since mid-2020. From May 2020 to February 2022, the FAO's Food Price Index rose by 55.2%, with fuel prices reaching their highest level since 1990. The World Bank (2023a) reported that domestic food price inflation remains high in most countries, especially in Africa, North America, Latin America, South Asia, Europe, and Central Asia. The majority of high-income countries (87%) experience high food price inflation, which surpasses the general inflation rate (World Bank 2023a). In line with these findings, Fig. 2 shows the performance of the FAO food prices from 2000 to 2022, showing annual positive international food CPI growth of 3.3% during this period. The FAO Food Price inflation increased from 7% in 2021 to 16% in 2022. A report of International Monetary Fund (2022) attributed inflation rise in many economies even before Russian Ukraine war, to surged commodity prices and Covid-19 effect of supply–demand imbalances.

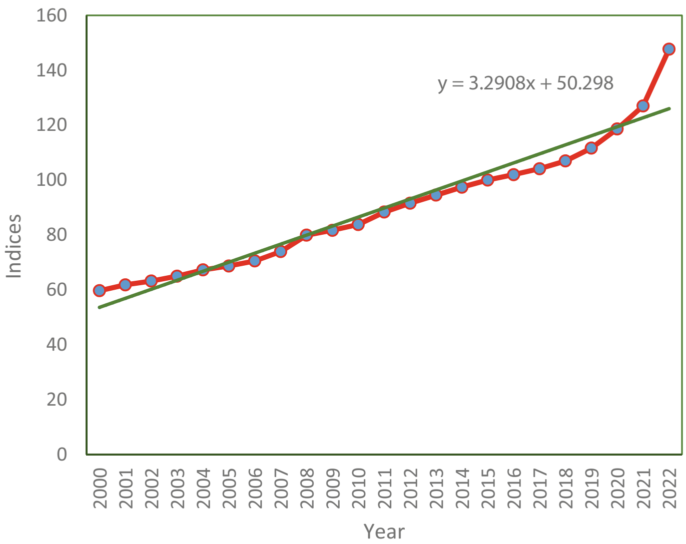


**Fig. 2** Performance of FAO's food price index (2015 = 100) from 2000 to September 2022. *Source* Prepared by the author based on data from FAOSTAT (2023)

## 3 Analysis of the Variability of Food Prices in Saudi Arabia

Saudi Arabia relies on food imports to meet local demand. According to World Bank data, food accounted for approximately 15% of merchandise imports in 2021 (World Bank 2023b), and food product imports increased by 30.4%, totaling 27.6 billion Saudi riyals (SR), with a share of 14.2% of total imports in 2022 (Ministry of Economy and Planning 2022). The country's dependence on imports is expected to continue due to limited local production caused by water scarcity and unfavorable weather conditions. This makes it challenging to maintain affordable food prices, causing concerns for Saudi Arabian food companies (Qureshi 2013). As a result, countries that spend more on food imports are more vulnerable to international price fluctuations, which can result in balance of payment problems (HLPE 2011).

### *3.1 Changes in Prices of Expenditure Categories in Saudi Arabia*

In Saudi Arabia, the primary method of measuring inflation is through the release of the monthly Consumer Price Index (CPI), which is published by the General Authority for Statistics (GaStat). Table 1 shows that the Housing, water, electricity, gas, and other fuels category is the most significant component of the CPI, making up 26% of the index. Food and non-Alcoholic beverages rank next, constituting approximately 19% of the CPI. Expenditure on transportation (13%) secured the third position in the consumer price index.

The overall consumer price index (CPI) recorded a 2.4% increase from January 2001 to June 2022, as illustrated in Fig. 3. Within this time frame, the inflation rate remained in the single digits, with 2008 experiencing the highest inflation rate at 9.9%. This may be attributed to the global financial crisis of 2008.

Table 2 illustrates the consumer price indices for the main expenditure categories during the period of 2015–2019. It reveals that in 2019, restaurants and hotels had the highest year over year inflation rate of 1.8%. Education ranked second with an increase of 1.5%, followed by food and beverages (1.2%) and miscellaneous goods and services (1%). On the other hand, the housing, water, electricity, gas, and other category recorded the highest decrease of 6.1% in year over year inflation rate. A report issued by the Saudi Central Bank states that during the third quarter of 2022, restaurants and hotels recorded the highest increase in year over year inflation rate at 7.1%. Education ranked second with 5.7%, followed by recreation and culture (4.2%). Food and beverages ranked fourth with a year over year inflation rate increase of 4.1% (Saudi Central Bank 2022). Comparing these results, it is evident that the top four expenditure categories with the highest inflation rates remained consistent between these two periods (i.e., 2019 and the third quarter of 2022), with Food and beverages ranking third in 2019 and fourth in the third quarter of 2022.

**Table 1** The relative significance of categories of spending in the calculation of the Consumer Price Index.in 2022

| Item | % (Base year 2018) |
|---|---|
| General index | 100.00 |
| Food and non-alcoholic | 18.78 |
| Tobacco | 0.60 |
| Clothing and footwear | 4.20 |
| Housing, water, electricity, gas and other fuels | 25.50 |
| Furnishings, household equipment | 6.74 |
| Health | 1.43 |
| Transport | 13.05 |
| Communication | 5.62 |
| Recreation and culture | 3.06 |
| Education | 2.87 |
| Restaurants and hotels | 5.60 |
| Miscellaneous goods and services | 12.57 |

*Source*General Authority for Statistics (2022)

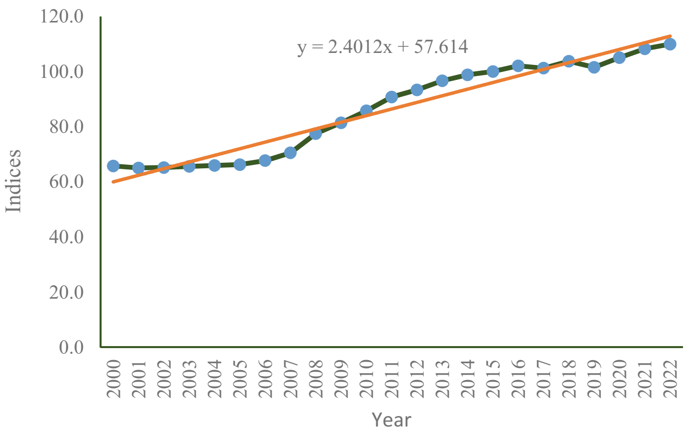


**Fig. 3** Consumer price indices (2015 = 100) in Saudi Arabia (January 2001–June 2022). *Source* Prepared by the author based on data from FAOSTAT (2023)

Saudi Central Bank (2023) revealed that in the first quarter of 2023, the general consumer price index exhibited 3.0% increase in year over year inflation rate, with Food and beverages ranked third (3.2%) in the main expenditure categories. Table 3 indicates that Food and beverages exhibit the highest average score of CPI relevant to the general index, Education, Restaurants and Hotels; and Recreation and Culture during the period of January–May 2023. It is also notable that Food and beverages

**Table 2** Consumer price indices for main expenditure categories (2013 = 100)

| Year | 2015 | 2016 | 2017 | 2018 | 2019 | % Change 2019 to 2018 |
|---|---|---|---|---|---|---|
| General index | 104 | 106 | 105 | 107 | 106 | − 1.2 |
| Food and beverages | 102 | 101 | 100 | 106 | 108 | 1.2 |
| Tobacco | 106 | 121 | 154 | 192 | 192 | 0.1 |
| Clothing and footwear | 107 | 113 | 112 | 110 | 103 | − 0.8 |
| Housing, water, electricity, gas, and other fuels | 103 | 103 | 101 | 103 | 103 | − 6.4 |
| Furnishings, household equipment and maintenance | 104 | 106 | 106 | 110 | 111 | 0.6 |
| Health | 102 | 110 | 108 | 119 | 120 | 0.8 |
| Transport | 106 | 109 | 110 | 110 | 112 | 0.6 |
| Communication | 103 | 103 | 104 | 111 | 113 | − 0.7 |
| Recreation and culture | 104 | 106 | 105 | 107 | 106 | − 0.4 |
| Education | 102 | 101 | 100 | 106 | 108 | 1.5 |
| Restaurants and hotels | 106 | 121 | 154 | 192 | 192 | 1.8 |
| Miscellaneous goods and services | 107 | 113 | 112 | 110 | 103 | 1.0 |

*Source* Prepared by the author based on data from General Authority for Statistics (2019)

hit the highest score in May. That increase is expected by Saudi central bank (2023) due to the following reasons.

(a) Upcoming of the holy seasons (Ramadan, Eid al-Fitr and al-Adha, and the Hajj).
(b) Policy impact of adjusting diesel prices from 63 to 75 halalas per liter by January 2023.
(c) Increasing domestic demand supported by the improvement in Saudis employment rate, tourism and leisure activities.

**Table 3** Consumer price index (2018 = 100) by expenditure category (January–April 2023) in Saudi Arabia

| Month | General index | Food and beverages | Education | Restaurants and hotels | Recreation and culture |
|---|---|---|---|---|---|
| January | 108.8 | 123.3 | 102.7 | 122.0 | 105.6 |
| February | 108.7 | 122.5 | 102.7 | 122.0 | 105.5 |
| March | 108.7 | 122.1 | 102.7 | 122.1 | 105.5 |
| April | 109.2 | 122.5 | 102.7 | 122.6 | 108.5 |
| May | 109.4 | 122.6 | 102.7 | 122.3 | 109.0 |
| Average | 108.9 | 122.6 | 102.7 | 122.2 | 106.8 |

*Source* General Authority for Statistics (2023b)

**Table 4** Rate of change of CPI (2018 = 100) of the year 2023 from the Same Month of 2022 (%)

| Month | General index | Food |
|---|---|---|
| January | 3.35 | 4.33 |
| February | 2.96 | 3.08 |
| March | 2.74 | 2.19 |
| April | 2.70 | 0.79 |
| May | 2.77 | 0.73 |

*Source* General Authority for Statistics (2023b)

Table 4 shows that the inflation of food is outnumber the general index in January and February 2023, and it is lower than March to May general index. Furthermore, the inflation of food reach of maximum of 4.33% in January during the period of January–May 2023.

The food price index in Saudi Arabia showed an annual increase of 3.2% between January 2001 and June 2022, as shown in Fig. 4. It is worth noting that the rate of increase in food indices tends to be higher than that of general price indices (2.4%) during the same period. Furthermore, the figure indicates a steady increase in food indices from 2020 onwards.

The continuous increase in food prices could have a negative impact on household spending and purchasing power. However, food producers may benefit from higher prices, increasing their income and improving their living standard. Saudi Arabia experienced an annual food price inflation rate of 0.03% from January 2001 to June 2022, as shown in Fig. 5. The highest recorded food inflation rate was in 2008 with double digits, reaching 11.7% due to the world financial crisis. In 2020, food inflation ranked second with a rate of 9% which was mainly due to the impact of the Covid-19 pandemic on food supply and trade measures.

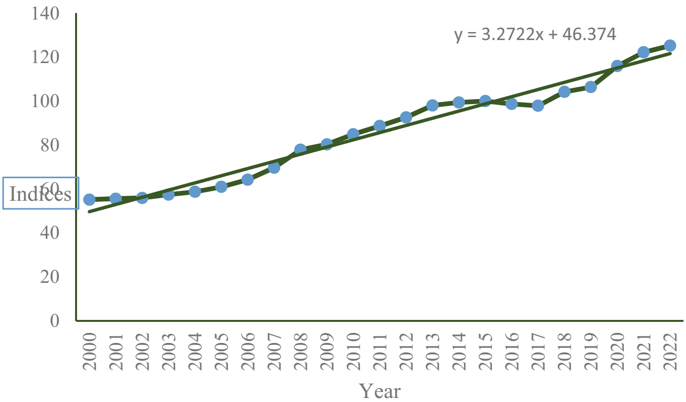


**Fig. 4** Food price indices (2015 = 100) in Saudi Arabia (January 2001–June 2022). *Source* Prepared by the author based on data from FAOSTAT (2023)

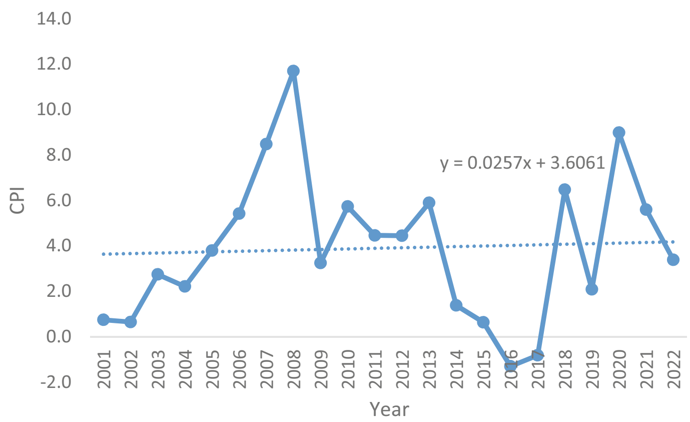


**Fig. 5** Performance of food price inflation in Saudi Arabia (January 2001–June 2022). *Source* Prepared by the author based on data from FAOSTAT (2023)

## 4 Changes in Average Prices of Some Food Commodities in Saudi Arabia

Food commodities are important to both consumers and farmers, with the availability of food greatly affected by prices, which are in turn subject to diverse sources of variation, ultimately affecting food security. According to the General Authority for Statistics (2023a), there was a price increase in food products exceeding a 5% increase relative to the previous month in January 2023. These food products include yogurt (33.3%), local melon (19.7%), local zucchini (15.8%), local watermelon (14.6%), local cucumbers (13.97%), local grapes (13.6%), Lebanese peach (8.2%), local okra (5.97%), medium Lebanese pears (5.3%), and white cabbage (5.1%).

## 5 Changes in Average Prices of Food Groups in Saudi Arabia

Food groups are collections of foods that perform the same functions in the body. These groups include starchy foods, fruits and vegetables, legumes and pulses, nuts and seeds, meat, fish, and animal protein products, milk and milk products, fats and oils, and sugar and sweets (Ministry of Health 2017). In Saudi Arabia, according to the General Authority for Statistics (2023a), food and beverages are divided into subgroups, including bread and seeds, meat and poultry, milk, milk products, and eggs, oils and fat, fruits and nuts, vegetables, sugar, and sweets, coffee and tea, mineral water, soft drinks, and juices. To examine the annual price changes of these food groups, some food commodities were selected to represent the main food groups as shown in Table 5.

**Table 5** Main food and beverage groups in Saudi Arabia

| Food groups (in kg, otherwise indicated) | Commodity |
|---|---|
| Bread and seeds | White and brown local flour (average) |
| | Maza and basmati Indian rice (average) |
| Fruits and nuts | Yellow and red apples (average) |
| | Abu sorra egyptian orange |
| Vegetables | Ekhilas dates, (Maknoz) |
| | Local cucumbers |
| | Local okra |
| | Green beans |
| | Local black eggplants |
| | Local zucchini |
| | Local tomatoes |
| Meat and poultry (900 gm) | Fresh cattle, sheep, camel and imported chilled meat (average) |
| | Local fresh chicken (Faqih and (Al Wataniya) and imported frozen (average) |
| | Fresh Fish (Kanaad and Grouper) (average) |
| Milk (1.5 L), milk products (500 gm) and eggs (1 plate) | Local Fresh Milk ((Al Marai and Al Safi) (average) |
| | Local glass cheese (Al Marai) |
| | Local eggs |
| Oils (1.5 L) and tat (100 gm) | Vegetable oil, (frying) Al Arabi and corn oil, (cooking), Afia (average) |
| | Butter( Lurpak) |
| Sugar and tweets | Soft sugar (alosra) |
| | Imported Honey (Langilies) |
| Coffee and tea | Black loose tea (Rabea) |
| | Coffee beans, Hrari |
| Mineral water (1.5 L), soft drinks (320 ml) and juices (180 ml) | Water |
| | Local soft drinks |
| | Orange local juice (Rani) |

*Source* Prepared by the author from General Authority for Statistics data (2023a)

## *5.1 Changes in Average Prices of Bread and Seeds in Saudi Arabia*

The annual fluctuation in rice prices was around 0.89 Saudi riyals between 2009 and 2022, with the highest price occurring in 2015. In contrast, the price of bread remained relatively steady, increasing by around 0.05 Saudi riyals annually during the

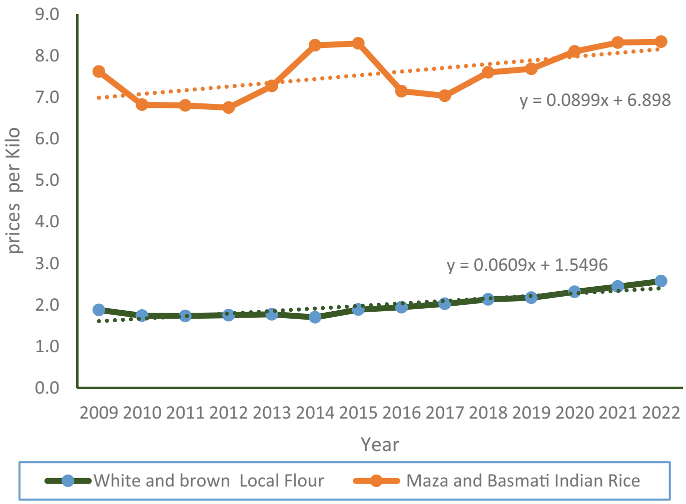


**Fig. 6** Changes in average prices of bread and seeds in Saudi Arabia (2009–2022). *Source* Author preparation based on data from General Authority for Statistics (2023a)

same period. In 2022, prices have continued to rise, largely due to high international prices and concerns over a potential shortage in supplies resulting from the conflict between Russia and Ukraine (Fig. 6).

### 5.2 Changes in Average Prices of Fruits and Nuts in Saudi Arabia

The average price of oranges reached its peak in 2020, mainly due to the spread of the Covid-19 pandemic and the higher demand, as it constitutes a major source of Vitamin C. The annual increase in the price of apples amounted to 0.13 SR during the period of 2009–2022 (Fig. 7).

### 5.3 Changes in Average Prices of Vegetables in Saudi Arabia

The prices of various vegetables such as cucumber, local okra, green beans, local zucchini, local black eggplants, and local tomatoes follow similar trends between 2009 and 2022. Local okra and green beans were the most expensive during this time period, as shown in Fig. 8.

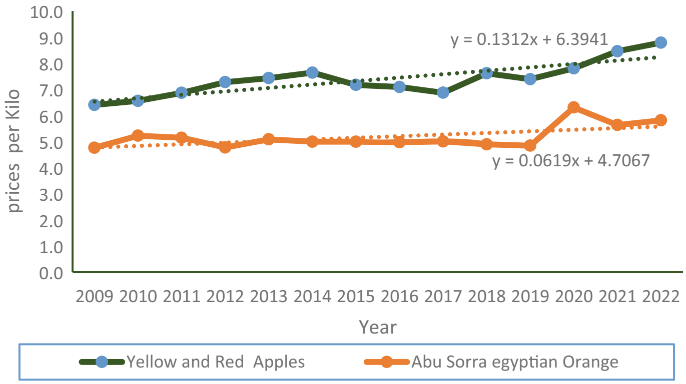


**Fig. 7** Changes in average prices of fruits and nuts in Saudi Arabia (2009–2022). *Source* Author preparation based on data from General Authority for Statistics (2023a)

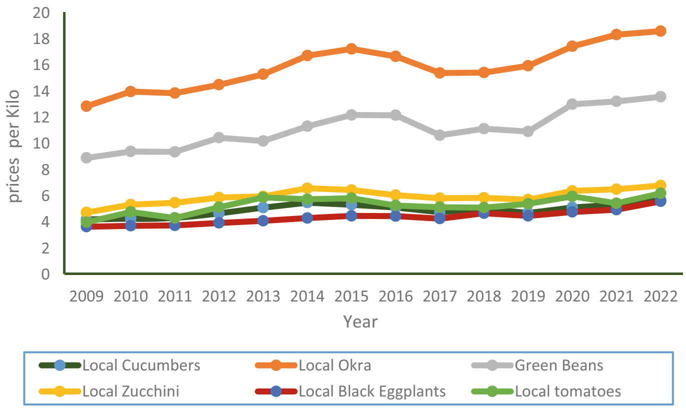


**Fig. 8** Changes in average prices of Vegetables in Saudi Arabia (2009–2022). *Source* Author preparation based on data from General Authority for Statistics (2023a)

### *5.4 Changes in Average Prices of Meat and Poultry in Saudi Arabia*

Chicken meat had the lowest price level with minimal variation compared to red meat and fish from 2009 to 2022. This can be attributed to the ample supply from domestic sources. During the years 2015–2021, fish prices had the highest price levels, but there was a decrease in prices in 2022. The highest annual price increase was recorded in red meat (1.2 SR), followed by fish (1.0 SR), and chicken (0.4 SR) from 2009 to 2022 as shown in Fig. 9.

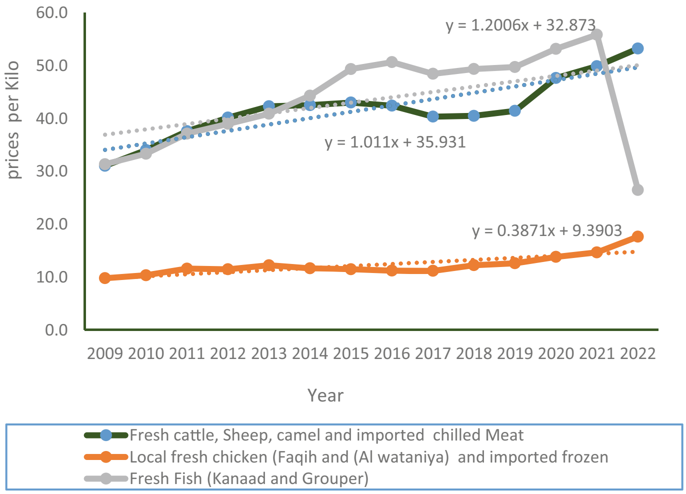


**Fig. 9** Changes in average prices of Meat and Poultry in Saudi Arabia. *Source* Author preparation based on data from General Authority for Statistics (2023a)

### *5.5 Changes in Average Prices of Milk Products and Eggs in Saudi Arabia*

Fresh milk had the lowest price and showed little variation compared to local glass cheese and local eggs between the years 2009 and 2022. Local glass cheese and local eggs exhibited a wide range of variation, with an annual price change of 1.2 and 0.39 Saudi Riyals, respectively, during the same period (Fig. 10).

### *5.6 Changes in Average Prices of Oils and Fat in Saudi Arabia*

The average prices of vegetable oil and butter witnessed an annual increase of 0.22 and 0.21 Saudi Riyals, respectively, between 2009 and 2022. The price of butter remained relatively stable between 2009 and 2017. It is noteworthy that the prices of vegetable oil and butter reached their highest level in 2022, which may be attributed to the invasion of Russia and Ukraine (Fig. 11).

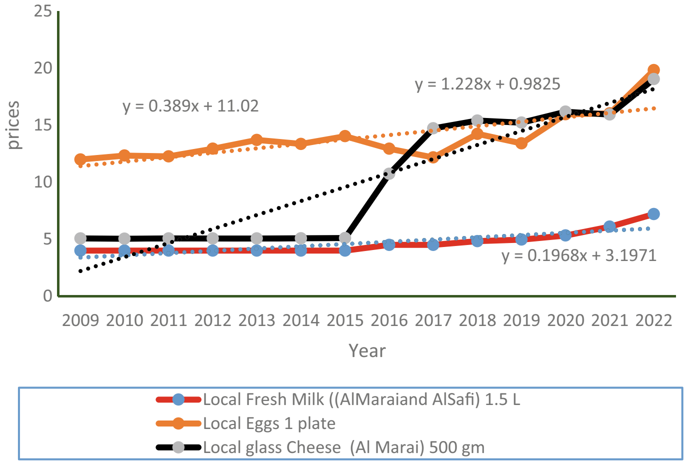


**Fig. 10** Changes in average prices of, milk products and eggs in Saudi Arabia during 2009–2022. *Source* Author preparation based on data from General Authority for Statistics (2023a)

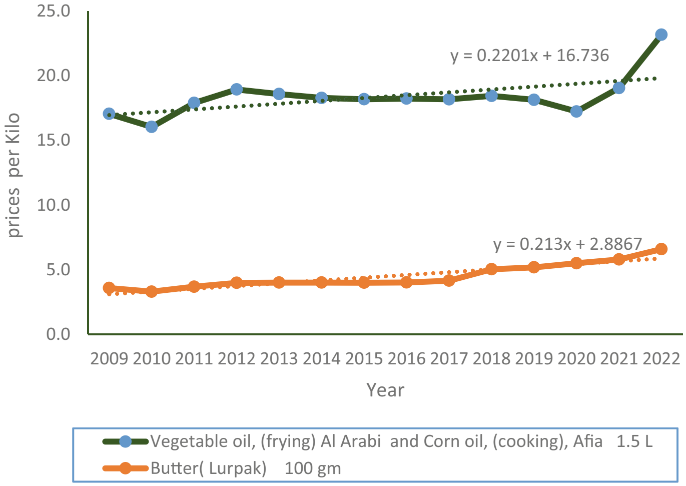


**Fig. 11** Changes in average prices of Oils and Fat in Saudi Arabia during (2009–2022). *Source* Author preparation based on data from General Authority for Statistics (2023a)

## *5.7 Changes in Average Prices of Sugar and Sweets in Saudi Arabia*

The average price of sugar showed an annual decrease of 0.21 SR, while imported honey experienced a 2.3 SR increase during the period of 2009–2022. The sugar price reached its maximum level in 2011and its lowest in 2016 (Fig. 12).

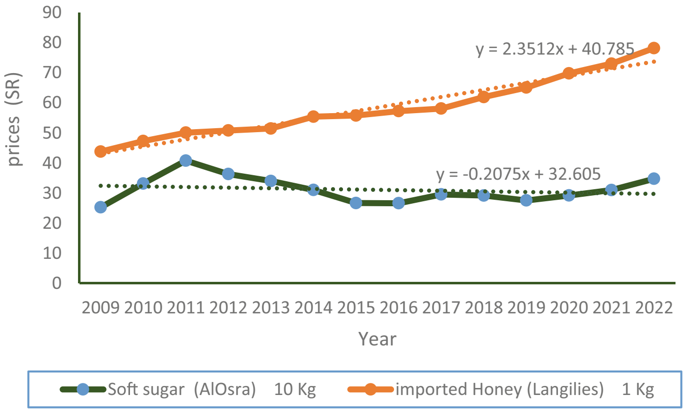


**Fig. 12** Changes in average prices of sugar and sweets in Saudi Arabia during (2009–2022). *Source* Author preparation based on data from General Authority for Statistics (2023a)

## *5.8 Changes in Average Prices of Coffee and Tea in Saudi Arabia*

The price of coffee has shown an increasing trend during the periods of 2009–2013 and 2021–2022. Conversely, the price of tea has shown a declining trend during the same periods. In general, the annual increase in the price of coffee (1.4 SR) is higher than that of tea (0.55 SR) during the 2009–2022 period, as shown in Fig. 13.

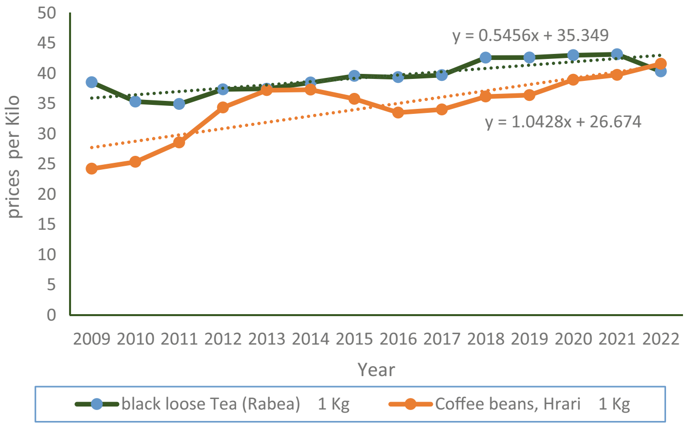


**Fig. 13** Changes in average prices of Coffee and Tea in Saudi Arabia during (2009–2022). *Source* Author preparation based on data from General Authority for Statistics (2023a)

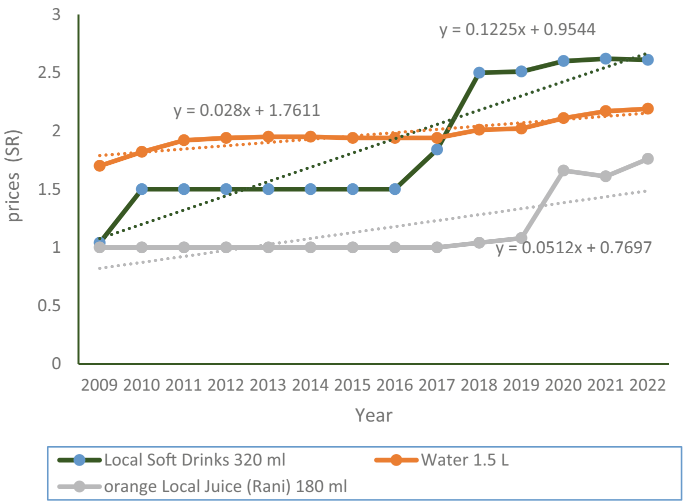


**Fig. 14** Changes in average prices of mineral water, soft drinks, and juices in Saudi Arabia during (2009–2022). *Source* Author preparation based on data from General Authority for Statistics (2023a)

### *5.9 Changes in Average Prices of Mineral Water, Soft Drinks, and Juices*

Soft drinks sold locally experienced more price fluctuations than orange juice and mineral water between 2009 and 2022. Soft drinks saw an annual increase in price of 0.12 SR, while orange juice saw an increase of 0.05 SR and mineral water saw an increase of 0.02 SR. The figure also reveals that each of these products reached its highest price point in 2022 as shown in Fig. 14.

## 6 Conclusion and Prospects

Food prices play a significant role in food security at the household, country, and global levels. Soaring food prices have raised concerns within the international community, as it is considered a threat to global food security. In Saudi Arabia, the general consumer price index (CPI) has seen an annual increase of 2.4%, while food price inflation expressed an annual increase of 0.03% between January 2001 and June 2022. Food and beverage products recorded year over year inflation rates of 1.2% and 4.1% in 2019 and 2022, respectively. This increase can be attributed to the adverse effects of the Covid19 pandemic. The period between 2009 and 2022 witnessed an increase in average commodity prices with imported honey experiencing the highest annual price increase followed by coffee, red meat, local glass cheese, and fish. Price volatility directly impacts food security, as a continuous increase in food price inflation would adversely affect the spending and purchasing power of households on access to nutritious and healthy food. Thus, a food-security strategy is needed to overcome the negative impact of food price hikes. Government policies that enhance agricultural efficiency, social protection and trade openness will eventually decrease the effects of price volatility.

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# Chapter 3
# The Impact of Oil Revenue on Food Security in Saudi Arabia

**Nagat Elmulthum, Abda Abdalla Emam, and Heba Althawaini**

**Abstract** Saudi Arabia economy is highly dependent on oil revenue. Hence, all sectors including food sector have gains from the oil sector directly or indirectly. This chapter aimed at studying and analyzing the impact of oil revenue on food security in Saudi Arabia. Emphasis was placed on availability and accessibility pillars of food security. Descriptive and quantitative analysis were employed using Microsoft excel and STAT statistical packages. Results indicated the prominence of food imports in import bill in Saudi Arabia which rank second in terms of import value after machinery, mechanical appliances, and electrical equipment imports. Quantitative analysis indicated long run relationship between food imports and oil revenue, oil revenue significantly affects food imports. The effect of price inflation caused by correction of energy prices in 2016 and 2018 had led to increased energy prices reflected in increased prices of food and nonfood items. Based on results, higher levels of the general price index were associated with increased food and beverages index with anticipated impact on accessibility to food. Moreover, a rise in transport price index is associated with an increase in price index of food and beverages. Further, results revealed high correlation between oil revenue and food security related sectors including human resource and development, economic resource development, health and social development, subsidies, transport, and communications sectors. The contribution of oil revenue to expenditure in these sectors assured the priority given by policy makers to food security related sectors. Based on research results authors suggest more weight on non-oil sector to bridge the gap in oil returns

N. Elmulthum (✉) · A. A. Emam · H. Althawaini
Department Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: nelmultham@kfu.edu.sa

A. A. Emam
e-mail: aaeali@kfu.edu.sa

H. Althawaini
e-mail: 218005133@student.kfu.edu.sa

N. Elmulthum
Department of Agricultural Economics, Faculty of Agricultural Sciences, University of Gezira, Wad Madani, Sudan



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during cycles of slumps and low oil prices. In addition, adjustments of energy prices should be planned in the framework of the influence on local prices, consequently on food prices. Further research on the effect of oil prices on food prices conveyed through transport cost is recommended.

**Keywords** Availability · Accessibility · Correlation · Co-integration · Oil price · Spillover effect

## 1 Introduction

In order to achieve food security, the first step is to address the unequal distribution of food at both regional and national levels. This starts with ensuring that there is enough food available. However, it's important to note that availability alone is not sufficient for achieving food security, as the food may not be accessible to those who need it the most. Another important factor is acceptable utilization, which refers to the body's ability to absorb and metabolize food. In order to ensure proper utilization of food, it is necessary to have nutritious and safe diets, as well as proper healthcare to prevent diseases. Stability is also a crucial aspect of food security, as it distinguishes between chronic malnutrition and food insecurity caused by seasonal variations in production or temporary disruptions due to natural or man-made disasters (Gross et al. 2000), According to Guiné et al. (2000), food security consists of four dimensions: availability, accessibility, utilization, and stability. This concept is closely related to the Sustainable Development Goals (SDGs), specifically goal two of zero hunger. It is important to note that the level of gross domestic product has a greater impact on the availability of food and nutrients than on undernutrition.

Burchi and De Muro (2016) provided a comprehensive review of the various approaches to food security analysis. According to their review, the oldest and most crucial approach is the food availability approach. This approach focuses on the balance between food and population. Their argument suggests that maintaining the balance requires the growth rate of food availability to be at least equal to the growth rate of the population. Therefore, food security can be simply understood as having enough food available per person. In a closed economy, this relies on the production of food and food stocks, while in an open economy, it depends on global food trading. Another macroeconomic approach has revisited the interpretation of food security as solely a matter of food availability. Economists who concentrate on one single economic sector have criticized the emphasis on the food sector, specifically agricultural production and food trading. They argue that the economy is made up of various interdependent sectors, so food security should not be limited to the food sector alone. Consequently, efforts have been made to shift the analysis towards national economies and include variables that can influence food production and imports.

According to Davis et al. (2016), increasing human consumption and climatic variability have generated large uncertainties regarding international food trade and its consequences on the food security of countries. To reduce dependency on imported food, many nations have concentrated on raising their domestic food production. However, targets for maintaining food self-sufficiency through increasing production necessitate incorporation of avenues for improving resource use efficiency, where the increase in rice production in Sri Lanka resulted in high increases of water consumption. Because of water scarcity in Saudi Arabia food self-sufficiency is a target of high cost, Saudi Arabia is highly dependent on food imports (Rady et al. 2016).

In 2015, Kang conducted a study on the impact of trade on food security. Kang used panel data from 2000 to 2010 to examine this relationship in less developed countries. The results of the study were consistent across different methods and showed a U-shaped association between global trade and food security. Initially, the study found that food security deteriorated during the early stages of trade expansion. However, beyond a certain point, food security improved. The main finding of this study is the U-shaped relationship between trade and food security. These results suggest that policymakers should focus on investing in agricultural productivity, particularly with regards to self-sufficiency and self-reliance.

Timmer (2000) argued that policies and outcomes in the economy have a significant influence on agriculture and rural economics. He recommended strategies that involve economic growth without altering income distribution, as well as growth accompanied by income redistribution. Using data on maize and petrol prices in East Africa, Dillon and Barrett (2016) presented evidence on the relationship between oil prices and food prices in developing nations. The analysis revealed that international oil prices do impact food prices, but this impact is transmitted through transportation costs. The effect of global oil prices on domestic food prices exceeded the effect of global food prices. Specifically, changes in international oil prices have a greater impact on domestic maize prices compared to changes in world maize prices.

Reboredo (2012) examined the relationships between international oil prices and international prices for wheat, corn, and soybean. They utilized copula models with different restricted dependence frameworks and estimated time-changing dependence parameters. The findings from January 1998 to April 2011 revealed a low correlation between oil and food prices, indicating that changes in oil prices did not strongly influence food prices. Additionally, there was no significant market dependence between oil and food prices. However, during the final three years of the study period, the dependence increased significantly, although it remained insignificant. This suggests that higher oil prices did not cause substantial increases in food prices. These results contradict the findings reported by Dillon and Barrett (2016).

Ibrahim (2015) analyzed the relationship between food and oil prices in Malaysia adopting a nonlinear autoregressive distributed lags model. Results indicated the existence of cointegration between variables, which comprise oil price, food price, and real gross domestic product. Regression results proved long run significant relation between oil price and food price. Moreover, in the short run there is a positive significant relationship between oil price and food price inflation. Results obtained by Ibrahim (2015) match the results obtained by Dillon and Barrett (2016).

According to Herrmann (2009), high levels of food self-sufficiency could help promote the situation of food security for local people. However, boosting food production is viable only in countries having agricultural potential. In other countries, especially suffering water scarcity, Saudi Arabia being one of them, food production is a challenge incurring high opportunity cost. At the national level, food security depends on ability of countries to meet local consumption through local food production and to create adequate economic resource to finance essential food imports.

Using United States and international data, To and Grafton (2015) employed autoregressive models to estimate the relationship between food prices and oil prices, gross domestic product per capita, and biofuels production. The results showed that biofuels production and crude oil had a statistically significant impact on food prices in both the United States and internationally. Specifically, during the international food price spike in 2008, it was found that 38 and 41% of the increases in food prices in the United States and internationally were attributed to the rise in US biofuels production and the US crude oil price, respectively. Similarly, increases in international biofuels production and the international crude oil price were responsible for 19% and 40% of the rise in international food prices, respectively.

In their study, Pieters and Swinnen (2016) explored the issue of food security in Saudi Arabia, considering the country's heavy reliance on food imports. They adopted an international perspective and utilized a water-energy-food connection framework to analyze the relationship between energy availability, water scarcity, food production, and consumption in Saudi Arabia. The findings revealed that Saudi Arabia implemented certain measures to reduce the use of scarce water resources for local feed and food production. However, this situation also made the country susceptible to fluctuating and elevated international market prices, particularly for cereals.

Since the 1970s, the Gulf Cooperation Council (GCC) has witnessed fast growth in population and economic development, induced by intense increases in oil revenues. growth in population coupled with higher levels of industrialization, urbanization, and agricultural production has put immense pressure on the region's scarce water resources. GCC countries are using extremely higher levels of water than sustainable recharge would permit. Their water footprints, are sustained by unconventional water sources including desalination, reuse of wastewater and the importation of "virtual" water through agricultural goods (Saif et al. 2014).

Chen, Kuo and their colleagues conducted a study in 2010 to examine the connections between crude oil prices and global prices of corn, soybean, and wheat. The findings indicated that fluctuations in the price of each grain were greatly influenced by changes in the price of crude oil and the prices of other selected grains between the third week of 2005 and the 20th week of 2008. This suggests that, when crude oil prices are high, there is increased competition for grains due to the demand for biofuels made from soybean or corn.

Nazlioglu and Soytas (2011) conducted a study on the correlation between global oil prices, exchange rates, and agricultural commodity prices (such as maize, wheat, cotton, sunflower, and soybeans) in Turkey. They used the Toda-Yamamoto causality methodology and generalized impulse response analysis to analyze monthly data from January 1994 to March 2010. The results showed that there was no significant impact of oil price and exchange rate shocks on agricultural prices in the short term. The analysis also revealed that changes in oil prices and fluctuations in the Turkish lira did not affect agricultural commodity prices in Turkey in the long term. Therefore, the findings indicated that the agricultural commodity markets in Turkey are not influenced by direct or indirect effects of oil price changes.

According to Sultan and Haque (2018), the international price of crude oil has a significant impact on Saudi Arabia's economic wealth. The government heavily relies on revenue from oil exports to regulate its economic activities. Oil exports are also crucial for earning foreign exchange needed for the country's imports. Therefore, any disruption in this sector would have a ripple effect on Saudi Arabia's entire economy. The authors used the Johansen cointegration method to examine the long-term relationship between economic growth, oil exports, imports, and government consumption expenditure in Saudi Arabia. The results show a positive long-term relationship between economic growth and both oil exports and government consumption expenditure. On the other hand, a negative long-term association is found between imports and economic growth. The study suggests regulating imports and diversifying the economic base through import-substituting industries.

Mahmood et al. (2020) argued that Saudi Arabia, an oil-rich country, heavily relies on the oil sector for its income. However, this over-dependence on the oil sector leads to an increase in greenhouse gas emissions caused by economic growth. The authors conducted a study to estimate the effects of factors such as per capita non-oil income, the income share of the oil sector, urbanization, and the price of gasoline on per capita carbon dioxide emissions ($CO_2$e) in Saudi Arabia from 1970 to 2014. They employed a nonlinear cointegration technique to calculate the asymmetrical effects of the oil sector on $CO_2$e and found evidence of a long-term relationship. The results indicated that urbanization and non-oil income had a positive effect on per capita $CO_2$e, while the price of gasoline had a negative effect. Additionally, a positive asymmetrical effect of the income share from the oil sector on $CO_2$e was observed. The study concluded by recommending the implementation of strict environmental policies in the formulation of economic policies and a decrease in the economy's reliance on the oil sector, in order to achieve a cleaner environment.

Bah and Saari (2020) conducted a study to examine how reforms in energy prices affected the living expenses of different household groups in Saudi Arabia. To model these effects, they utilized an input–output table in conjunction with household expenditure data. The findings revealed that the distributional impact of the energy price reforms was regressive. Specifically, households with lower incomes experienced a greater increase in living expenses compared to higher-income households. This disparity can be primarily attributed to the rise in prices of energy-intensive products. By analyzing the effects in terms of direct and indirect impact, the researchers found that the indirect effect played a significant role in driving up spending on energy-intensive items within households. As a result, the study recommended policymakers to review and modify the social protection system to shield impoverished households from the consequences of these reforms.

Jibril et al. (2020) conducted a study on the unequal impacts of oil supply shocks, shocks to global economic activity, and oil-specific demand shocks on the trade balances of a large sample of oil-exporting and oil-importing countries. The study used an empirical approach that considered factors such as endogenous oil prices, varying parameters, and error cross section dependence within a panel framework. The findings revealed that the relationship between oil prices and trade balances exhibited asymmetries depending on the source of the shock. For both oil importers and exporters, developments in oil supply had a more significant impact than disruptions in oil supply. Saudi Arabia played a role in managing the global effects of oil supply disruptions. Additionally, it was observed that increases in global demand negatively affected the trade balances of oil importers, while benefiting those of oil exporters.

Results enhance the standing signal that oil price rises produce large international imbalances when they are outcome of demand-side shocks.

In 2020, Rostan and Rostan predicted the economic indicators of the Saudi economy in the context of low oil prices from 2014 to 2017. As an economy heavily reliant on oil, the decrease in trades and investments led to significant budget deficits. To address this, the Saudi government introduced the Saudi Vision 2030 in 2016. This initiative implemented structural economic reforms to transition from an oil-dependent economy to a modern market economy. The research utilized spectral analysis of the Saudi economy to forecast economic indicators up to 2030. The aim was to provide a more comprehensive understanding of the future economy, assuming that the impact of current policies had not yet been reflected in economic indicators. The results suggested that oil prices were estimated to average $64.40 from 2019 to 2030. Additionally, the Saudi population was projected to reach 40 million by 2030. The increased gross domestic product (GDP) generated by the non-oil sector was a result of the bold actions taken by the Saudi government to reduce reliance on oil revenues. By utilizing spectral forecasts, government policymakers and investors could gain valuable insights into the dynamics of the Saudi economy during the early stages of significant economic improvements. However, the COVID-19 pandemic in 2020 negatively impacted the Saudi economy due to a decline in global oil demand and an oversupply in the market. The extent of the effect on the Saudi economy will depend on the actions taken by the Saudi government in response. Given the reforms and challenges facing the economy, the forecasting of Saudi economic indicators is of critical importance.

In order to measure the dependency of Saudi Arabia on the crude oil sector, Jawadi and Ftiti (2019) conducted a study on the impact of oil price variations on the country's economic growth. The results of the study confirmed that the oil sector plays a significant role in the economic growth of Saudi Arabia. However, the results also revealed that the relationship between the Saudi economy and oil exhibited nonlinearity and threshold effects, implying that the impact of oil price varied depending on the state of the market. Additionally, the research findings align with the goals of Vision 2030, favoring the transformation of the economy and the opening of the stock market. The study found a positive and significant impact of stock investment on the Saudi Arabian economy. Encouraging diversification will further enhance the beneficial effects of the oil sector on the real economy.

Gonand et al. (2019) conducted a study on the intergenerational welfare effect of increasing controlled retail energy prices in Saudi Arabia, a country that exports oil. They developed a dynamic model with overlapping generations to analyze the impacts of the price increase that was implemented in December 2015. The model examined the effect of price increases on the welfare of Saudi citizens by looking at both direct increases in energy expenditures and indirect increases in Saudi public income. The analysis suggested that the increase in retail energy prices had a overall beneficial impact on the long-term welfare of all households. This can be attributed to the effect on the revenue of private individuals from the surplus in public oil income resulting from reduced national consumption of oil products, which is then given back to private individuals. Additionally, the additional oil income derived from the higher national energy prices is more valuable for future generations when it is reinvested through public investment.

The effects of oil price shocks on food nutrition prices in oil-importing countries initially decrease and then adjust over multiple periods. However, these effects are gradual and significant for oil-exporting countries (Shokoohi and Saghaian 2022).

## 2 The Impact of Oil Revenue on Food Security

The impact of oil revenue on food security will be discussed from two essential dimensions of food security. Authors will focus on availability and accessibility dimensions of food security. Availability of food is a macro issue where; policy makers are concerned with availability of food derived, either from local production or from imports. Accessibility could be viewed from both macro and micro perspectives, where oil revenue and oil prices would spill over to consumers at the individual level.

### *2.1 Oil Revenue and Food Imports*

Food availability defines the first dimension of food security (Tanya et al. 2018), it represents the supply side of food security. However, to secure adequate nutritional status, at the national level food security requires an efficient structure of food, health, economic systems, coupled with high levels of consideration of climate change and environmental consequences. Food availability could be achieved through food production and or relying on imports. Saudi Arabia is an oil exporting country, economically dependent on oil revenue. As illustrated by Fig. 1. Steady rise in oil revenue in Saudi Arabia is observed during the period 2002–2006, more or less constant during 2006–2007, a sharp increase in 2008, and an observable drop in 2009. Lopez-Murphy and Villafuerte (2010) argued that Organization of the Petroleum Exporting Countries (OPEC) degraded their non-oil core balances considerably during the period 2003–2008 motivated by an increase in major spending. However, this trend was to some extent overturned when oil prices sharply decreased in 2009, which is reflected in oil revenue The oil industry was impacted by lower oil prices in 2014. The decrease in oil prices since mid-2014 has been caused by various factors, such as unexpected increases in unconventional oil production, a decline in global demand, a significant change in OPEC's policy, reductions in geopolitical risks, and the strengthening of the U.S. dollar. As a result, the drop in oil prices will result in significant changes in income from oil exporters to oil importers, ultimately having a positive impact on overall economic activity in the medium term. However, this decline in oil prices will also present substantial challenges for fiscal, monetary, and structural policies (Baffes et al. 2015).

Non-oil revenue is increasing slightly from 2002 to 2008, then at an intermediate pace during 2008–2013 to a comparatively higher pace during 2014–2019, which may attributed to the high consideration given to non-oil sectors (Saudi Vision 2016), Fig. 2.

The contribution of oil and non-oil revenues to total revenue in Saudi Arabia is shown in Fig. 3, which illustrated a wide gap favoring oil sector, however, the period 2014 onwards witnessed increased contribution of the non-oil sector which reflect polices in Saudi Arabia towards encouragement and enhancement of non-oil sector in line with Saudi 2030 Vision (Saudi Vision 2016).

Figure 4 depicts the value of imports of selected items including products of chemicals and allied industries, food imports, base metals and articles of based metals, machinery, mechanical appliances and electrical equipment's. Food imports rank

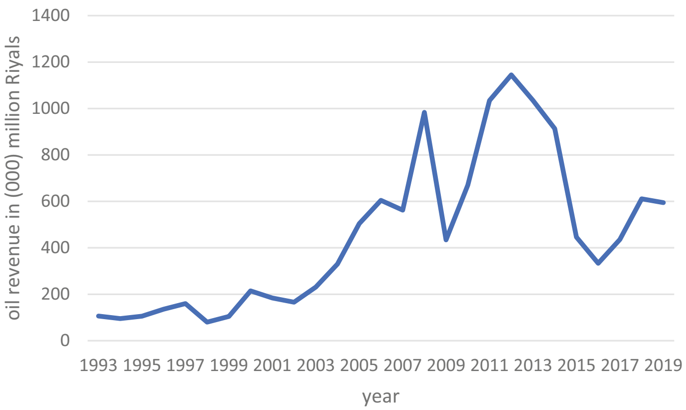


**Fig. 1** Oil revenue (in (000) million Riyals) 2000–2019. *Source* Authors presentation based on Annual statistics of Saudi Monetary Fund (2018, 2019, 2020)

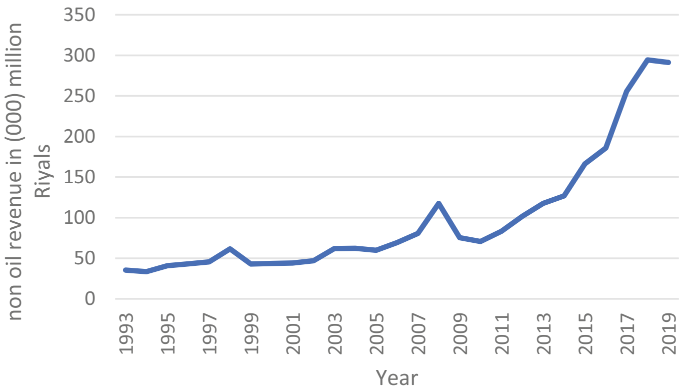


**Fig. 2** Non-oil revenue in (000) minion Riyals 2000–2019. *Source* Authors presentation based on Annual statistics of Saudi Monetary Fund (2018, 2019, 2020)

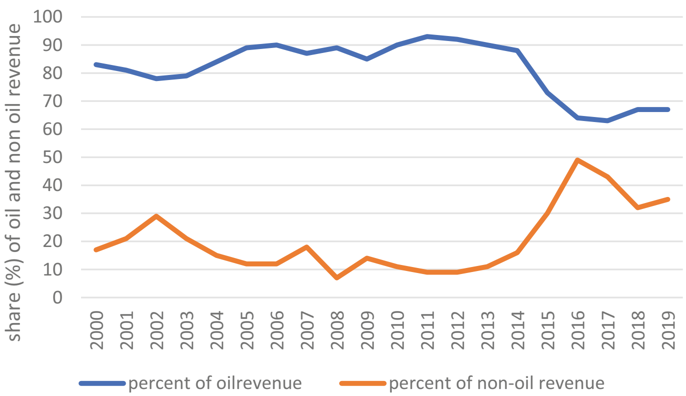


**Fig. 3** Share (%) of oil and non-oil revenue out of total revenue in Saudi Arabia during 2000–2019. *Source* Authors calculations and presentation based on Annual statistics of Saudi Monetary Fund (2018, 2019, 2020)

second in importance in terms of import value after machinery, mechanical appliances, and electrical equipment. The figure reflects the relative importance of food imports in imports bill in Saudi Arabia. This is finding is in line with Pieters and Swinnen (2016) argument of high dependency on food imports for meeting food demand in Saudi Arabia. The impacts of shocks in oil prices on food nutrition prices in oil *importing countries* are at first declining and then adapts over numerous periods However, for *oil exporting countries* these effects are incremental and significant Shokoohi and Saghaian (2022).

To analyze the relationship between food imports and oil revenue we used the following specification:

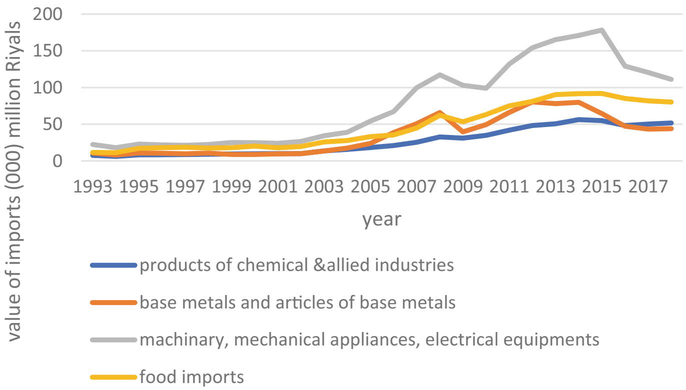


**Fig. 4** Value of imports of selected items in Saudi Arabia in (000) million Riyals during the period 1993–2018. *Source* Authors presentation based on Annual statistics of Saudi Monetary Fund (2018, 2019, 2020)

$$Y = \alpha X^{\beta} \tag{1}$$

where, Y denotes food imports, X denotes oil revenue. α, β are the regression coefficients

The log linear form of Eq. (1) above was estimated using the following specification

$$lnY = Ln\alpha + \beta LnX \tag{2}$$

Before doing the regression analysis we tested the stationary of data using Augmented Ducky Fuller (ADF) test. In addition, Johansen Co integration test and Vector Error Correction (VECM) were used to test the long run relationship between the variables namely food imports as a dependent variable and oil revenue as an explanatory variable.

Results of Augmented Ducky fuller test revealed that at level variables for Ln food imports (Y) and Ln oil revenue (X) indicated acceptance of the null hypothesis, implying that the data has a unit root test and hence not stationary supplementary Tables 2 and 3 of the appendix. However, at the first difference both variables are stationary at 5% level of significance, supplementary Tables 4 and 5.

Based on final prediction error criterion (FPE) and Hannan Quinn Information (HQIC) criterion the number of lags to be included as regressors for running VECM equals two lag periods supplementary Table 6 of the appendix. It was clear from the output in the supplementary Table 7 that the hypothesis of no cointegration equation is rejected, meaning that cointegration exits between food imports and oil revenue. The VECM can correct its previous time disequilibrium when the value of the coefficient of correction parameter is negative and illustrates significance. The coefficient of the correction parameter for food imports (as dependent variable) is negative (−0.24) and significant (Critical z value = − 2.59 with prob. = 0.01), suggesting that model is capable of correcting its previous time disequilibrium, supplementary Table 8 of the appendix.

Applying ordinary least square method to Eq. (2) we obtained the following equation.

$$lnY = 1.13 + 0.75LnX$$

Results in supplementary Table 9 showed that coefficients and the overall model are significant at 0.05 level. Seventy five percent of the variation in food imports is explained by variations in oil revenue. Results are further confirmed by high correlation (94%) between oil revenue and food imports, supplementary Table 9.

## 2.2 *Oil Revenue and Access to Food*

This section analyses and discusses the relationship between oil and non-oil revenue to accessibility to food by consumers in Saudi Arabia, where accessibility to food represent one of the important pillars of food security.

Per capita oil and nonoil revenue, depicted in Figs. 5 and 6, follow the same patterns of the upward and down trends of total oil and non-oil revenue which reflect the spillover effect of revenue on consumers. The increased per capita non-oil revenue is in line with the objective Saudi Vision 2030 (2016) which emphasized diversifying of Saudi economy as one of the most important elements of its sustainability. Oil and gas are core elements of Saudi economy; however, the vision stressed the expansion of investment in non-oil sectors for boosting the economy.

Consumption of diesel topped the consumption of gasoline during 2005–2015, as shown by Fig. 7, however, consumption of diesel dropped sharply in 2017. This

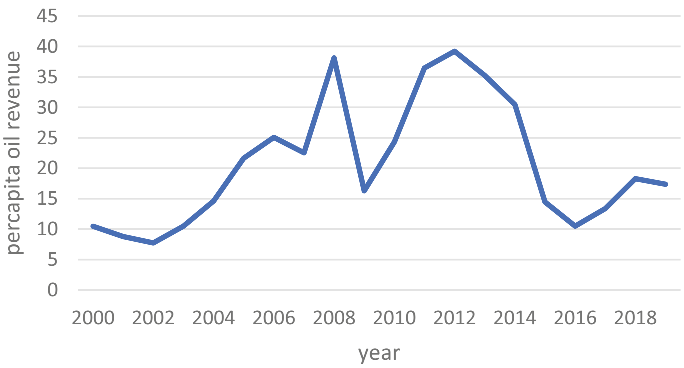


**Fig. 5** Per capita oil revenue (000 riyals) 2000–2019. *Source* Authors presentation based on Annual statistics of Saudi Monetary Fund (2018, 2019, 2020)

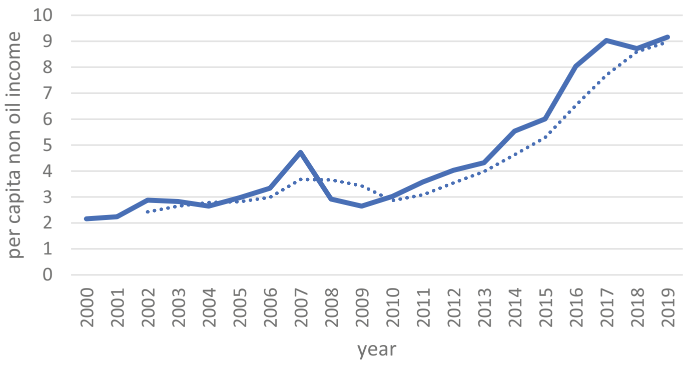


**Fig. 6** Per capita non-oil income in 000 riyals 2000–2019. *Source* Authors presentation based on Annual statistics of Saudi Monetary Fund (2018, 2019, 2020)

may be attributed to the increases in consumer prices affected by increased domestic oil prices in Saudi Arabia. The drop in gasoline consumption is expected to have reflection on food and nonfood consumption, where movement of items is usually by trucks which depend on diesel fuel.

Figure 8 depicts local prices of diesel, gasoline 90 and gasoline 95 during the period 2000–2019. Domestic prices of oil were constant during 2000–2005, then dropped in 2006, at constant level to 2015, then increased in 2016 onwards, where correcting energy prices and reduction of subsidies had led to increased energy prices specially for gasoline 95, and 90, with further correction in energy prices was implemented in 2018. The increased level of prices was reflected in increased prices of food and nonfood items. Based on (AlJubran, Kinawy et al. 2021), using Granger Causality test, one way causality from domestic oil prices to consumer food price index was detected. The above results support (To and Grafton 2015) results.

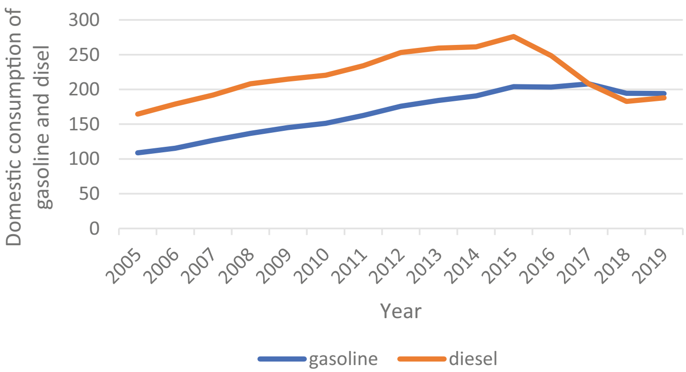


**Fig. 7** Domestic consumption of gasoline and diesel (million barrels) 2005–2019. *Source* Authors presentation based on Annual statistics of Saudi Monetary Fund (2018, 2019, 2020)

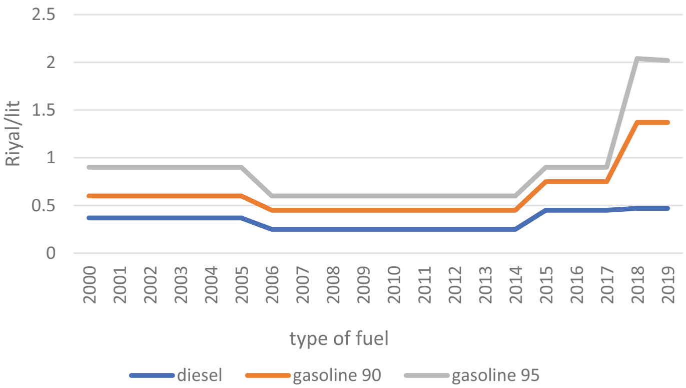


**Fig. 8** Price of diesel, gasoline 90, and gasoline 95 during the period 2000–2019. *Source* Authors presentation based on Annual statistics of Saudi Monetary Fund (2018, 2019, 2020)

The Saudi Arabia had, adopted a variety of support programs to improve consumer welfare. Moreover, since the launch of Vision 2030, the Saudi Arabia has been keen not to trade off access to food as crucial pillar of food security, particularly for low-income citizens. Consequently, a program known as Citizen Account came into effect, which is part of the Fiscal Balance Program under Saudi Vision 2030, The Citizen Account is a monetary payment for economic expansions for low-income Saudi households that might face a threat to achieve the recommended level of food consumption for food secured households, (Saudi Vision 2017). Except for 2019 general price index topped food and beverages index, where the effect of inflation in prices is reflected on food and beverages index with expected impact on accessibility to food and hence, food security situation in Saudi Arabia (Fig. 9).

From Fig. 10, an increase in transport price index is associated with an increase in price index of food and beverages. This could be interpreted by the spill-over effect

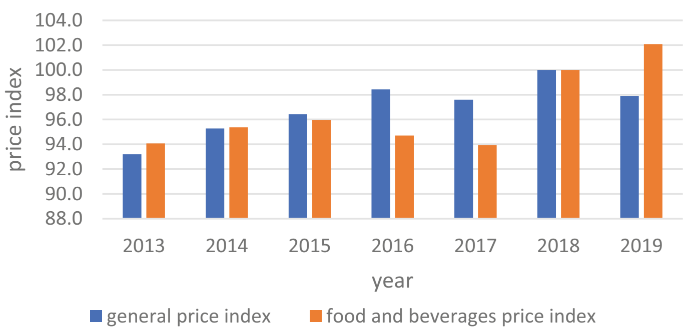


**Fig. 9** General consumer price index and food and beverages price index in Saudi Arabia (2013–2019). *Source* Authors presentation based on Annual statistics of Saudi Monetary Fund (2018, 2019, 2020)

of the increase in oil prices which is reflected in an increase of the cost of transport, as one of the marketing functions of goods and services including food items which would negatively affects food security situation. The above result supported the results by Dillon and Barrett (2016).

From Fig. 11 an increase in education price index is reflected in a reduction of food and beverages price index which could be interpreted by higher investment in education leading to consumers awareness in consumption of food items, hence, lessening the food and beverages index, with expected positive impact on food security.

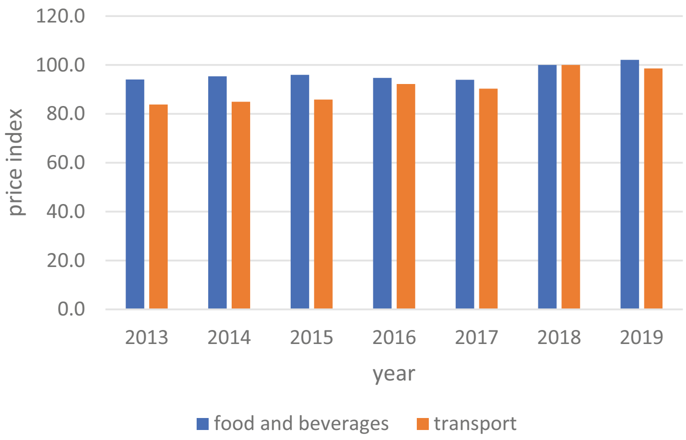


**Fig. 10** Consumer price indices for food and beverages and transport in Saudi Arabia (2013–2019). *Source* Authors presentation based on Annual statistics of Saudi Monetary Fund (2018, 2019, 2020)

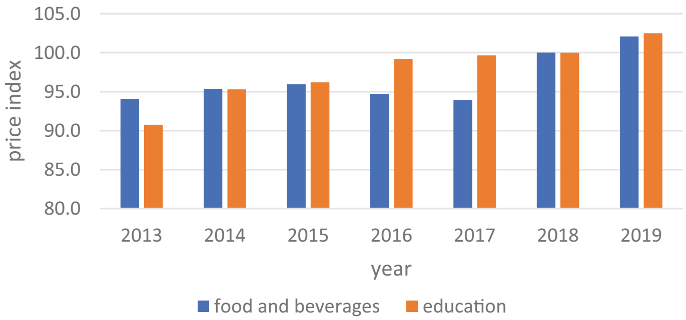


**Fig. 11** Consumer price indices food and beverages and education in Saudi Arabia (2013–2019). *Source* Authors presentation based on Annual statistics of Saudi Monetary Fund (2018, 2019, 2020)

## 3 The Impact of Oil Revenue on Food Security Related Sectors

This section examines the influence of oil revenue on the distribution of funds towards sectors related to food security. These sectors encompass human resource development, healthcare and social development, economic resource development, and subsidies.

The share of expenditure out of total oil revenue on sectors with expected impact on food security were estimated (Fig. 12). Human development sector ranked first followed by health and social development sector. Almost equal expenditure levels were observed for economic resource development, transport and communication and subsides sectors. The priority assigned to human development sector is expected to have a food security impact through improved levels of income coupled with enhanced awareness for Saudi citizen. Investment on health is expected to spill over on food security at the consumer level.

Table 1 Illustrated the correlation coefficients between oil revenue and expenditure on human resource and development, economic resource development, health and social development, subsidies, transport, and communications sectors. The highest correlation is observed between oil revenue and economic resource development sector, which is an indication of the importance given to economic resource development sector by policy makers. A correlation coefficient of 0.94 between oil revenue and expenditure on transport and communication reflects the importance of oil revenue on movement of goods and services including food items with expected implication on food security. High correlation between subsidies sector and oil

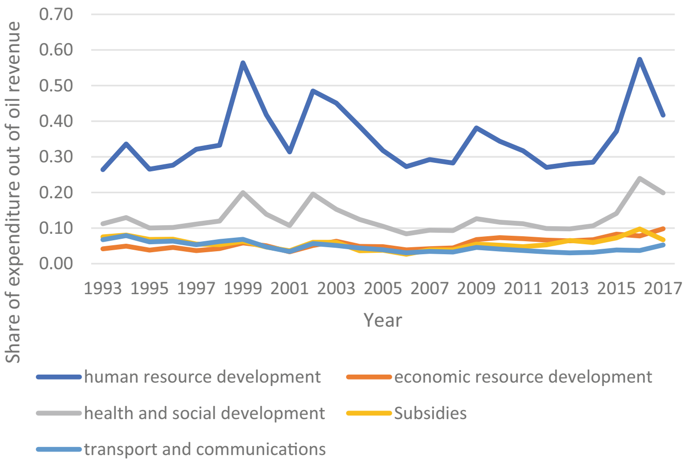


**Fig. 12** Share (%) of expenditure of some sectors out of total oil revenue in Saudi Arabia 1993–2017. *Source* Authors calculations and presentation based Annual statistics of Saudi Monetary Fund (2018, 2019, 2020)

**Table 1** Correlation between oil revenue in (million Riyals) and selected sector of crucial importance to food security

| | Oil revenue | Human resource development | Economic resource development | Health and social development | Subsidies | Transport and communication |
|---|---|---|---|---|---|---|
| Oil revenue | 1.00 | | | | | |
| Human resource development | 0.93 | 1.00 | | | | |
| Economic resource development | 0.96 | 0.97 | 1.00 | | | |
| Health and social development | 0.87 | 0.98 | 0.95 | 1.00 | | |
| Subsidies | 0.94 | 0.96 | 0.96 | 0.94 | 1.00 | |
| Transport and communications | 0.94 | 0.94 | 0.98 | 0.93 | 0.93 | 1.00 |

*Source* Authors calculations and presentation based on Annual statistics of Saudi Monetary Fund (2018, 2019, 2020)

revenue gives signs of the importance of oil revenue in supporting subsidies with expected spillover effect on consumers and producers and hence, food security.

## 4 Conclusion and Prospects

The purpose of this chapter is to examine and analyze how the revenue from oil has impacted food security in Saudi Arabia. The analysis focuses on two aspects: availability and accessibility of food security. Descriptive and quantitative techniques were used for the analysis. The findings showed that food imports ranked second in terms of import value, following imports of machinery, mechanical appliances, and electrical equipment. Furthermore, the quantitative analysis revealed a long-term relationship between food imports and oil revenue. Variation in oil revenue explained 75% of the variation in food imports, indicating a significant impact of oil revenue on food imports. In 2016 and 2018, energy prices were adjusted, leading to increased prices of both food and nonfood items. While oil and gas are crucial components of the Saudi economy, the vision for the future emphasizes the need to diversify investments in non-oil sectors to boost the economy. The improved per capita non-oil revenue aligns with the goals of Saudi Vision 2030, which prioritizes economic diversification as a key element for sustainability.

Higher levels of the general price index are linked to an increase in the food and beverages index. This reflects the impact of inflation on food and beverages prices and can affect access to food, thereby impacting food security in Saudi Arabia. Furthermore, an increase in the transport price index is connected to a rise in the price index of food and beverages. This can be attributed to the spillover effect of increased oil prices, which leads to higher transportation costs for goods and services, including food items. As a result, food and beverages prices increase, which has implications for food security. The study also found that there is a decrease in the price index of food and beverages associated with an increase in the education price index. This suggests that investments in education lead to increased consumer awareness, hence reducing the consumption of food items. This decrease in consumption results in a lower food and beverages index, which positively impacts food security. Policy makers prioritize sectors that have a spillover effect on food security, including human resource and development, economic resource development, health and social development, subsidies, transport, and communications sectors. These sectors show a high correlation with oil revenue. Therefore, the authors recommend focusing more on non-oil sectors during recessions and periods of low oil prices to compensate for the gap in oil revenue. It is also important to consider the impact of energy price corrections on local prices, especially food prices. Further research is recommended to understand the relationship between oil prices, transportation costs, and food prices.

## Appendix

Supplementary Tables 2, 3, 4, 5, 6, 7, 8 and 9

**Table 2** Ducky fuller test food imports variable (level variables)

| | | | | | | |
|---|---|---|---|---|---|---|
| dfuller Inreoilre, regress lags (1) | | | | | | |
| Augmented Dickey-Fuller test for unit root | | | | | Number of obs = 24 | |
| Interpolated Dickey-Fuller | | | | | | |
| | | Test statistic | 1% critical value | 5% critical value | 10% critical value | |
| Z(t) | | − 1.52 | − 3.75 | − 3.00 | − 2.63 | |
| Mackinnon approximate *p*-value for z(t) = 0.5253 | | | | | | |
| D.Inreoilre | Coef | Std. Err | t | $P > \|t\|$ | [95% Conf | Interval] |
| Inreoilre | | | | | | |
| L1 | − 0.15 | 0.10 | − 1.52 | 0.14 | − 0.36 | 0.06 |
| LD | − 0.02 | 0.21 | − 0.10 | 0.92 | − 0.46 | 0.42 |
| _Cons | 0.66 | 0.39 | 1.69 | 0.11 | − 0.15 | 1.48 |

*Source* Authors calculations using Saudi Monetary Fund official data (2018, 2019, 2020) and STATA statistical package

**Table 3** Ducky fuller test oil revenue variable (level variable)

| | | | | | | |
|---|---|---|---|---|---|---|
| Dfuller Inreafoimp, regress lags (1) | | | | | | |
| Augmented Dickey-Fuller test for unit root | | | | | Number of obs = 24 | |
| Interpolated Dickey-Fuller | | | | | | |
| | | Test statistic | 1% critical value | 5% critical value | 10% critical value | |
| Z(t) | | – 1.52 | – 3.75 | – 3.00 | – 2.63 | |
| Mackinnon approximate *p*-value for z(t) = 0.5262 | | | | | | |
| D. Inreafoimp | Coef | Std. Err | t | $P > \|t\|$ | [95% Conf | Interval] |
| Inreafoimp | | | | | | |
| L1 | – 0.06 | 0.04 | – 1.51 | 0.15 | – 0.15 | 0.02 |
| LD | – 0.07 | 0.21 | – 0.34 | 0.74 | – 0.50 | 0.36 |
| _Cons | 0.34 | 0.17 | 1.99 | 0.06 | – 0.01 | 0.70 |

*Source* Authors calculations using Saudi Monetary Fund official data (2018, 2019, 2020) and STATA statistical package

**Table 4** Ducky fuller test oil revenue variable (first difference)

| | | | | | | |
|---|---|---|---|---|---|---|
| tsset year, yearly | | | | | | |
| Time variable: | | | Year, 1994–2018 | | | |
| Delta: | | | 1 year | | | |
| dfuller dinreoil, regress lags (1) | | | | | | |
| Augmented Dickey-Fuller test for unit root | | | | | Number of obs = 23 | |
| Interpolated Dickey-Fuller | | | | | | |
| | | Test statistic | 1% critical value | 5% critical value | 10% critical value | |
| Z(t) | | – 4.19 | – 3.75 | – 3.00 | – 2.63 | |
| Mackinnon approximate *p*-value for z(t) = 0.0007 | | | | | | |
| D.dlnreoil | Coef | Std. Err | t | $P > \|t\|$ | [95% Conf | Interval] |
| Dlnreoil | | | | | | |
| L1 | – 1.35 | 0.32 | – 4.19 | 0.00 | – 2.03 | – 0.68 |
| LD | 0.26 | 0.22 | 1.18 | 0.25 | – 0.20 | 0.72 |
| _Cons | 0.10 | 0.09 | 1.08 | 0.29 | – 0.09 | 0.28 |

*Source* Authors calculations using Saudi Monetary Fund official data (2018, 2019, 2020) and STATA statistical package

**Table 5** Ducky fuller test food imports variable (first difference)

| | | | | | | |
|---|---|---|---|---|---|---|
| dfuller dinrefimp, regress lags (1) | | | | | | |
| Augmented Dickey-Fuller test for unit root | | | | | Number of obs = 23 | |
| Interpolated Dickey-Fuller | | | | | | |
| | | Test statistic | 1% critical value | 5% critical value | 10% critical value | |
| Z(t) | | – 3.43 | – 3.75 | – 3.00 | – 2.63 | |
| Mackinnon approximate *p*-value for z(t) = 0.0100 | | | | | | |
| D.dlinrefimp | Coef | Std. Err | t | $P > \|t\|$ | [95% Conf | Interval |
| Dlinrefimp | | | | | | |
| L1 | – 0.99 | 0.29 | – 3.43 | 0.00 | – 1.60 | – 0.39 |
| LD | 0.00 | 0.20 | 0.02 | 0.99 | – 0.41 | 0.41 |
| _Cons | 0.07 | 0.04 | 1.82 | 0.08 | – 0.01 | 0.14 |

*Source* Authors calculations using Saudi Monetary Fund official data (2018, 2019, 2020) and STATA statistical package

**Table 6** Results of lag selection

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Varsoc Inreoilre Inreafoimp | | | | | | | | |
| Selection-order criteria | | | | | | | | |
| Sample: | 1997–2018 | | | | Number of obs = 22 | | | |
| Lag | LL | LR | df | p | FPE | AIC | HQIC | SBIC |
| 0 | | | | 0.08 | 3.17 | 3.19 | 3.27 | |
| 1 | 96.94 | 4.00 | 0.00 | 0.00 | – 0.88 | – 0.80 | – 0.577526* | 96.94 |
| 2 | 11.99* | 4.00 | 0.02 | 0.0012* | – 1.06 | – 0.939611* | – 0.56 | 11.99* |
| 3 | 8.18 | 4.00 | 0.09 | 0.00 | – 1.06452* | – 0.90 | – 0.37 | 8.18 |
| 4 | 1.35 | 4.00 | 0.85 | 0.00 | – 0.76 | – 0.55 | 0.13 | 1.35 |
| Endogenous: | Inreoilre Inreafoimp | | | | | | | |
| Exogenous: | _cons | | | | | | | |

*Source* Authors calculations using Saudi Monetary Fund official data (2018, 2019, 2020) and STATA statistical package, * indicates significance at % level

**Table 7** Johansen cointegration results

| Johansen tests for cointegration | | | | | |
|---|---|---|---|---|---|
| Trend: | Constant | | | Number of obs = 24 | |
| Sample: | 1995–2018 | | | Lags = 2 | |
| Maximum rank | Parms | LL | Eigenvalue | Trace statistic | 5% critical value |
| 0 | 6 | 6.7379064 | | 20.6790 | 15.41 |
| 1 | 9 | 15.966029 | 0.53653 | 2.2228* | 3.76 |
| 2 | 10 | 17.077408 | 0.08846 | | |
| Vecrank Inreoilre Inreafoimp, trend (constant) | | | | | |

*Source* Authors calculations using Saudi Monetary Fund official data (2018, 2019, 2020) and STATA statistical package

**Table 8** Results of VECM

| Equation | Parms | RMSE | R-sq | Chi2 | $P > chi2$ | |
|---|---|---|---|---|---|---|
| D_ Inreafoimp | 4 | 0.127344 | 0.4617 | 17.15422 | 0.0018 | |
| D_Inreoilre | 4 | 0.421425 | 0.0732 | 1.578556 | 0.8126 | |
| | Coef | Std. Err | Z | $P > \|Z\|$ | [95 conf | Interval] |
| D_ Inreafoimp_ cel L1 | − 0.2404559 | 0.0927646 | − 2.59 | 0.010 | − 0.4222712 | − 0.0586406 |
| Inreafoimp LD | − 0.0445544 | 0.2373099 | − 0.19 | 0.851 | − 0.5096732 | 0.4205644 |
| Inreoilre LD | − 0.1565873 | 0.0906248 | − 1.73 | 0.084 | − 0.3342086 | 0.021034 |
| _cons | 0.08544 | 0.0310541 | 2.75 | 0.006 | 0.0245751 | 0.1463049 |

*Source* Authors calculations using Saudi Monetary Fund official data (2018, 2019, 2020) and STATA statistical package

**Table 9** Correlation results

| | Oil revenue | Food imports |
|---|---|---|
| Oil revenue | 1 | |
| Food imports | 0.93943 | 1 |

*Source* Authors calculations using Saudi Monetary Fund official data 1993–2019 and STATA statistical package

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# Chapter 4
# An Economic Analysis of the Plant Production Sector in Saudi Arabia

**Hanady Mustafa Abdelradi**

**Abstract** The target of this chapter is to study an economic analysis of the plant production sector in Saudi Arabia (KSA). In achieving its objectives, the chapter relied on the use of descriptive statistical analysis and analytical statistical standards through using averages, percentages, and annual growth rates for the variables under study. The chapter showed the most important cereal produced in Saudi Arabia are wheat, barley and sorghum. In addition, the most of Saudi Arabia's domestic cereals demand is covered by imports as KSA is considered one of the largest importers of barley, with an amount about 7000 thousand MT in 2020. On the other hand, the chapter reveals that the per capita consumption of vegetables and fruits in Saudi Arabia is small compared to other countries, and this is due to dietary habits. It also shows that green fodder is considered a major feed ingredient for cattle and sheep, except for cows. In 2020, the Saudi Arabia produced about million tons of green fodder. Alfalfa cultivated with about 99.89% of total green fodder area in KSA which was need about 6 billion cubic meters of water. Thus the chapter clears the role of the horizontal expansion and the vertical expansion to the increase in crop production.

**Keywords** Agriculture sector · Consumption · Economic analysis · Value added · Production

## 1 Introduction

Saudi Arabia agricultural sector contributes about 4% of the non-oil GDP in 2020 (MI Mordor Intelligence 2023), especially as the agricultural domestic production provides about 34% of the Saudi domestic needs. KSA seeks to raise the percentage of

H. M. Abdelradi (✉)
Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: habdelradi@kfu.edu.sa

Agricultural Economic Research Institute, Cairo, Egypt

 
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self-sufficiency in some food commodities through alternative solutions to enhance food security, such as agricultural investment abroad. On other hand one of the most important strategic programs is conserve water by encouraging farmers to participate in alternative sustainable agricultural activities, such as planting in greenhouses and implementing advanced drip irrigation practices for the production of fruits and vegetables. In addition, KSA strategy achieved to reduce food loss and waste through the supply chain, raising productivity, and developing modern agricultural practices. Therefore, the KSA established a national program to reduce food loss and waste. (UN environment program 2022) KSA also seeks to develop agricultural activities with a comparative advantage and economic feasibility by raising production rates, and this was evident in 2020 compared to 2019, as the production of cereals, vegetables, and fruits increased by 79%, 4%, and 68.7%, respectively (General Authority for Statistics 2023). KSA also seeks to diversify the KSA's revenues by encouraging programs that increase farmers' income, such as the Aryaf program for agricultural tourism and the establishment of the Saudi Agricultural and Livestock Investment Company (SALIC). This company is an advanced crop production analysis company through creating high-resolution maps using artificial intelligence; satellite images; and drone technology that aimed to developing and enhancing the agricultural sector and sustainable development (Elsharawy et al. 2019).

## 2 Agricultural Sector Performance Indicators During (2010–2020)

### *2.1 Value Added (2010–2020)*

Agricultural sector includes forestry, hunting, and fishing, as well as the cultivation of crops and livestock production. Added value is a term describing the difference between the value of goods and the cost of materials or supplies used in the production of those goods (Supriani and Pernamasari 2021).

Figure 1 shows the percent of agricultural value added in Saudi Arabia relative to the Gross Domestic Product (GDP) during the period 2010–2020. It showed that the agricultural value added increased from 13.95 billion USD in 2010 to 17.94 billion USD in 2020, with an increase of 28.60%. Contrarily, the percent of agricultural value added of GDP decreased from 2.64% in 2010 to 2.56% in 2020.

### *2.2 Agricultural Land*

The agricultural sector plays a major role in the Saudi economy, where agricultural activities provide the Saudi Arabia with food, but some agricultural activities have some negative effects represented in the deterioration of natural resources due to the

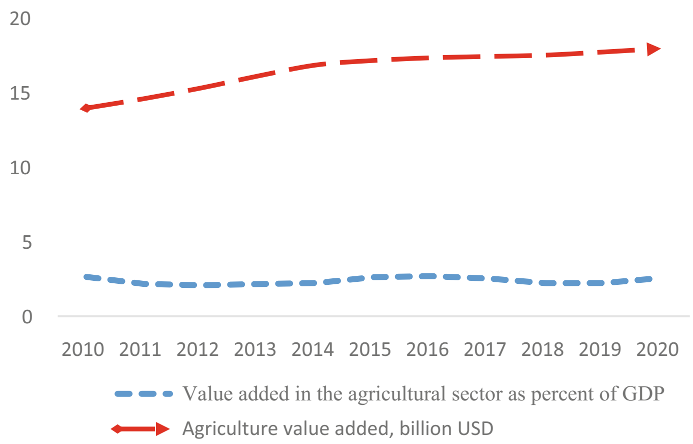


**Fig. 1** Saudi Arabia Agriculture value added during (2010:2020). *Source*: Authors' presentation based on data from World Bank Open Data (2023). https://data.worldbank.org/country/SA

unsustainable use of land and the inappropriate uses of other agricultural production inputs. Statistics indicate the increase in the area of agricultural lands to the total land of Saudi Arabia during the period 2010–2020. The results indicate a percentage increase from 80.67% in 2010 to 80.75%, with a growth rate of 0.023 (Figs. 2 and 3). The result also indicates that the percentage of agricultural holdings located in Asir and Makkah Al-Mukarramah regions represent the largest percentages in Saudi Arabia, with percentages contribution of 24.36% and 21.29%, respectively, and they contribute 19.29 and 16.29% of the total land cultivated.

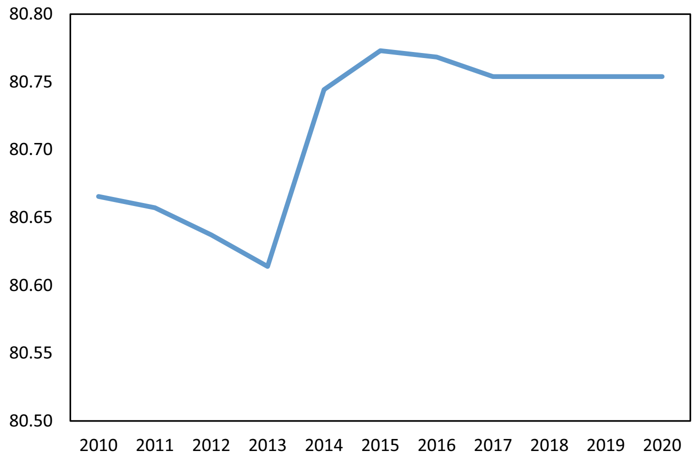


**Fig. 2** Cultivated land (% of land area)—Saudi Arabia (2010:2020). *Source* Authors' presentation based on data from World Bank Open Data; https://data.albankaldawli.org/country/SA

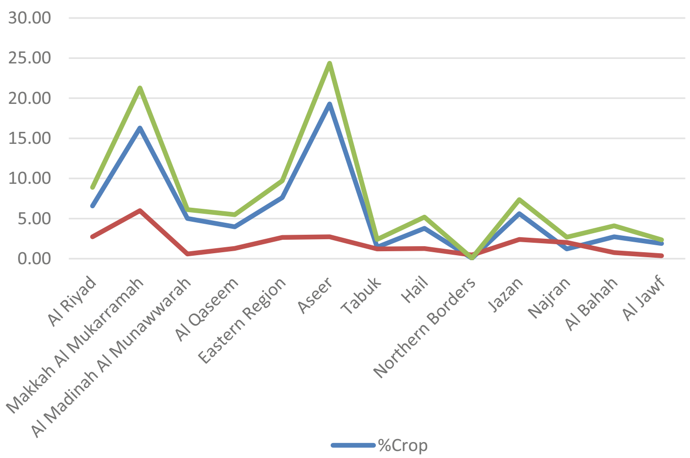


**Fig. 3** Percent of agricultural holdings and activities in Saudi Arabia (2010:2020). *Source* Authors' presentation based on data from General Authority for Statistics, Statistical Yearbook, Various Issues; https://www.stats.gov.sa/ar/258

## 3 The Economic Performance of Plant Production Sector in KSA (2010–2020)

### *3.1 Cereals*

Figure 4 illustrated the most important cereal that are produced in the Saudi Arabia are wheat, barley and Sorghum. as the percent of them are about 44.1%, 42.9% and 10.9% of total Cereal production in 2020 respectively.

Cereal production in KSA increased from 1570.94 thousand tons in 2010; to about 1730.50 thousand MT in 2020 with a growth rate of about 10.16%. While wheat production decreased from 1349 thousand MT in 2010 to only 764 thousand tons in 2020 with adecrease of about 43.38%. This is due to the suspension of the General Organization for Grains buying wheat from farmers. In 2014, the local production of barley was estimated at about 692 thousand MT, with a cultivated area of about 101.27 thousand hectares indicating an increase rate about 6043%, 6642% compared with the previous year 2013, respectively. local production of barley decreased after the implementation of the decision to cease fodder cultivation in October 2018 so barley production decreaded to 415 housand MT in 2019 with decrased rate of about 40.1%. Figure 5 showed that most of Saudi Arabia's domestic cereals demand is covered by imports as KSA is considered one of the largest importers of barley, with a amount about 7000 thouthand MT in 2020. This amount represents between more than 0.6% of the total quantities of barley offered for sale in the global markets with 12 MMT in 2020 (Index Mundi website 2023). The former General Grain Corporation

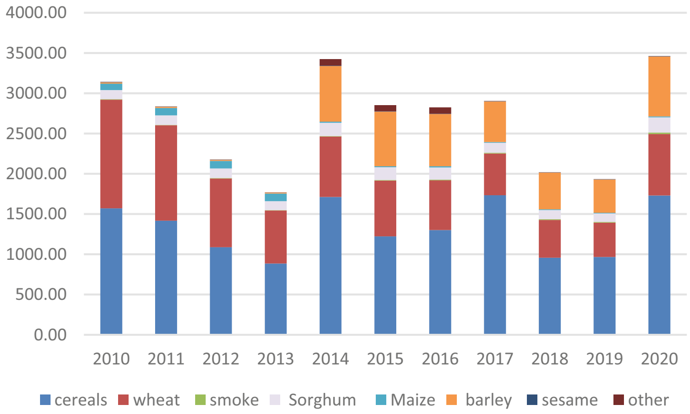


**Fig. 4** Cereals production in KSA during (2010:2020) by thousand MT in Saudi Arabia (2010:2020). *Source* Authors' presentation based on data from General Authority for Statistics, Statistical Yearbook, Various Issues; https://www.stats.gov.sa/en

has taken over the responsibility for importing barley directly, starting from October 2017 through a public tender for international suppliers.

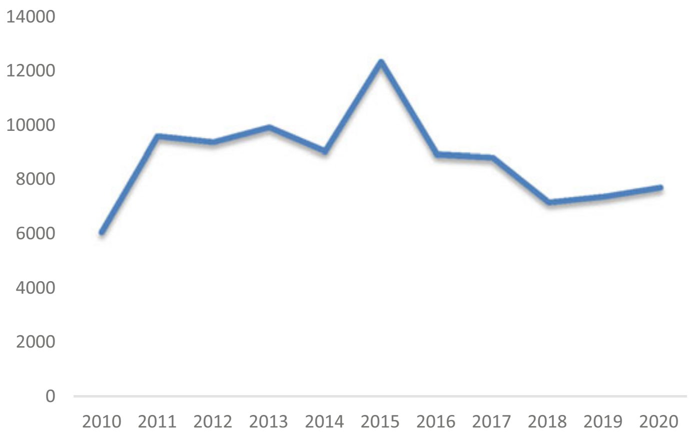


**Fig. 5** Barely imports (2010:2020) by 1000 MT in KSA. *Source* Authors' presentation based on data from Index Mundi. https://www.indexmundi.com/agriculture/?country=saandgraph=production

### 3.2 Vegetables

Figure 6 revealed that the per capita consumption/g/day of vegetables and fruits in Saudi Arabia is small compared to other countries, and this is due to dietary habits. The average per capita consumption of vegetables in 2020 was about 197.59 g per capita per day (Our World in Data 2023).

While, the average per capita vegetable intake versus the minimum recommended guidelines, 2020 WHO and national recommendations range from 200 to 250 g per day (World Health Organization 2020).

Figures 7 and 8 showed the production of watermelons, potatoes and tomatoes contributed to the total vegetable production of KSA by about 34.24%, 28.79% and 18.59%, respectively, which is equivalent to more than 80% of the total vegetable production in 2020. On the other hand, the area of watermelons and potatoes increased during the period (2010–2020) by 76% and 20% respectively. While the area of tomatoes decreased by 35%. The Production of watermelons and potatoes also increased by 47% and 5%, while the productivity of decreased during the same period by 17%, and 16%, respectively.

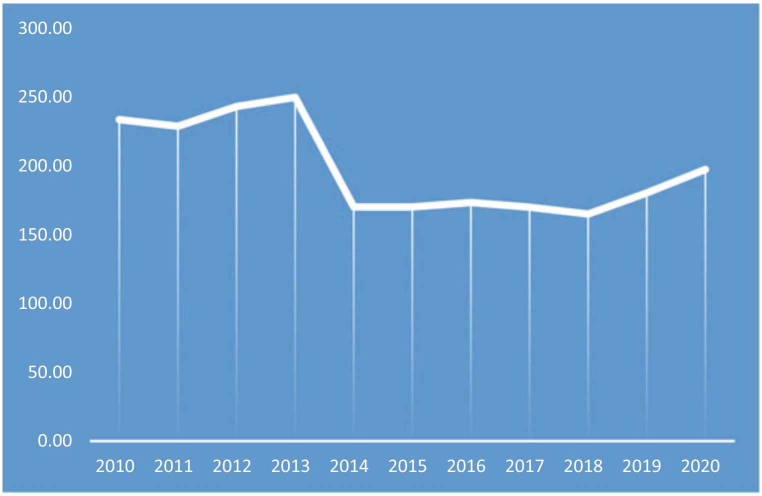


**Fig. 6** Average per capita vegetable consumption, measured in grams per person per day in KSA during (2010–2020). *Source* Authors' presentation based on data from website our world in data; https://ourworldindata.org/blog

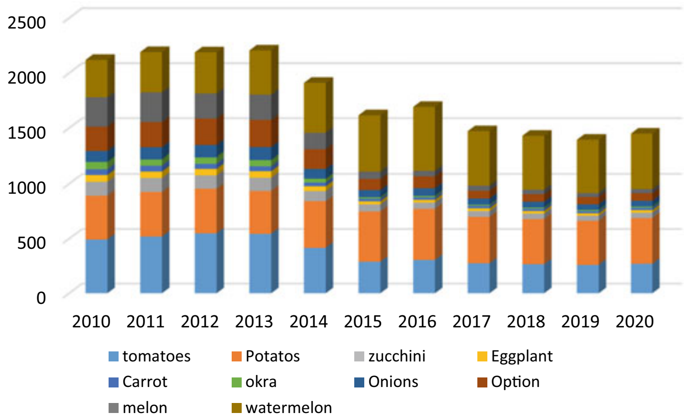


**Fig. 7** Vegetables production in KSA during (2010:2020) in thousand Mt in Saudi Arabia (2010:2020). *Source* Authors' presentation based on data from General Authority for Statistics, Statistical Yearbook, Various Issues; https://www.stats.gov.sa/en

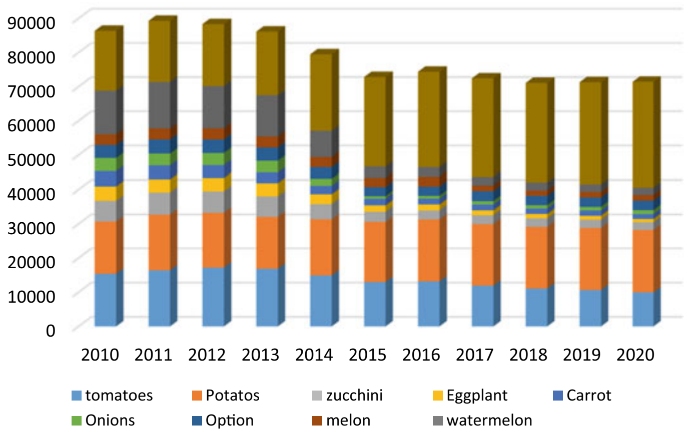


**Fig. 8** Vegetables cultivated Area (2010–2020) by ha in Saudi Arabia. *Source* Authors' presentation based on data from General Authority for Statistics, Statistical Yearbook, Various Issues; https://www.stats.gov.sa/en

## *3.3 Fruits*

Figure 9 showed the average per capita consumption of fruits amounted to 231.4 g per day that was more than the minimum average per capita consumption recommended by the World Health Organization was about 200 g per day.

According to Figs. 10 and 11, dates rank first in terms of fruit production, representing 87.56% of the total production and 80% of the total fruit area in 2020. On the other hand, the results indicate a decrease in the total area of fruit production in

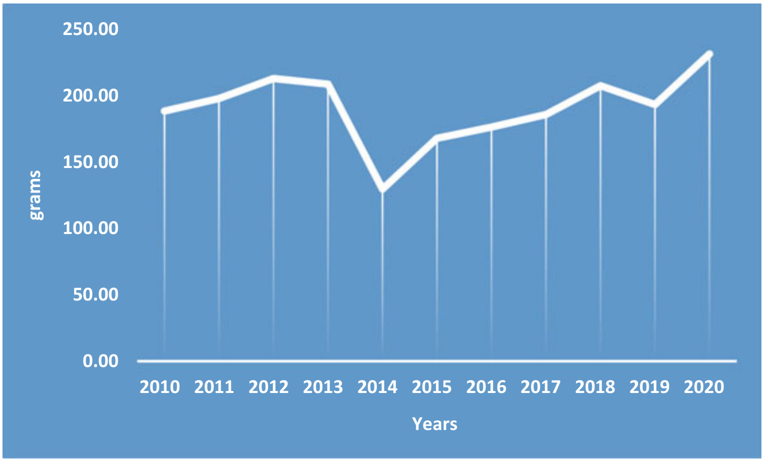


**Fig. 9** Average per capita Fruit consumption, measured in grams per person per day in KSA during (2010–2020). *Source* Authors' presentation based on data from website our world in data; https://ourworldindata.org/blog

2020 by 34% compared to the year 2010. Contrarily dates production increased by 89% and productivity increased by 187% during the same period, which indicates the use and adoption of more modern technologies in fruit cultivation.

Currently, there are about 400 types of dates in Saudi Arabia (Elsharawy et al. 2019). Dates production achieved a growth rate of 5% during the period 2010–2020. Moreover, the results indicate a decrease in the areas of some fruit crops, as the area of grapes, citrus fruits, and dates decreased by 64%, 54%, and 23%, respectively. It

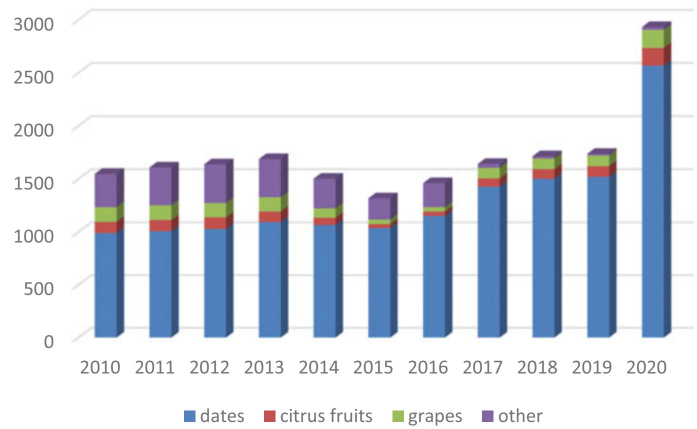


**Fig. 10** Fruits production in KSA during (2010:2020) by thousand tons in Saudi Arabia (2010:2020). *Source* Authors' presentation based on data from General Authority for Statistics, Statistical Yearbook, Various Issues; https://www.stats.gov.sa/en

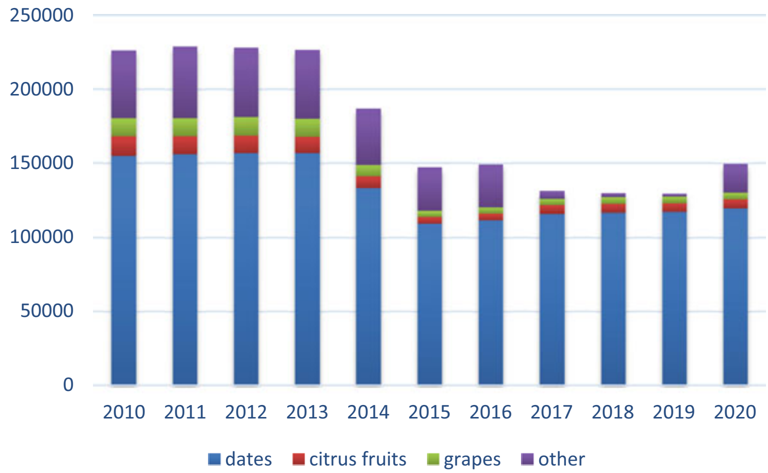


**Fig. 11** Fruits cultivated Area (2010–2020) by ha in Saudi Arabia. *Source* Authors' presentation based on data from General Authority for Statistics, Statistical Yearbook, Various Issues; https://www.stats.gov.sa/en

should be noted that the area of citrus fruits and grapes represented 4% and 3%, of the total area of fruits, respectively, during the same period.

### *3.4 Green Fodder*

Green fodder is considered as amajor feed ingredient for cattle and sheep, except for cows. In 2020, Kingdom produced about one million tons of green fodder. Where Alfalfa represents 99.89% of the total area of green fodder in Saudi Arabia, with a water need of about 6 billion cubic meters.

The Council of Ministers issued Decision 66 in March 2016 calling for ceasing the cultivation of forage while allowing small farmers (farms of less than 50 ha) to continue production or obtain compensation for ceasing or planting wheat as an alternative (General Authority for Statistics Various Issues). Despite this, the green fodder area increased by a growth rate of 4.4% during the period (2010–2020).

Figures 12 and 13 shows KSA produced about million MT of green fodder, in light of the decisions related to ceasing the cultivation of fodder, there was an urgent need to take several measures, including a re-evaluation of livestock breeding in terms of the number in Saudi Arabia, the development of the fodder industry, and the encouragement of agricultural investments abroad in the field of fodder cultivation.

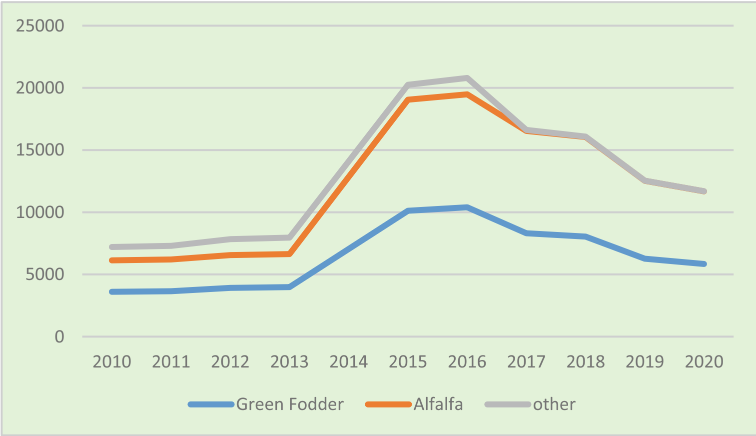


**Fig. 12** Green fodder production in KSA during (2010–2020) in thousand MT. *Source* Authors' presentation based on data from General Authority for Statistics, Statistical Yearbook, Various Issues; https://www.stats.gov.sa/en

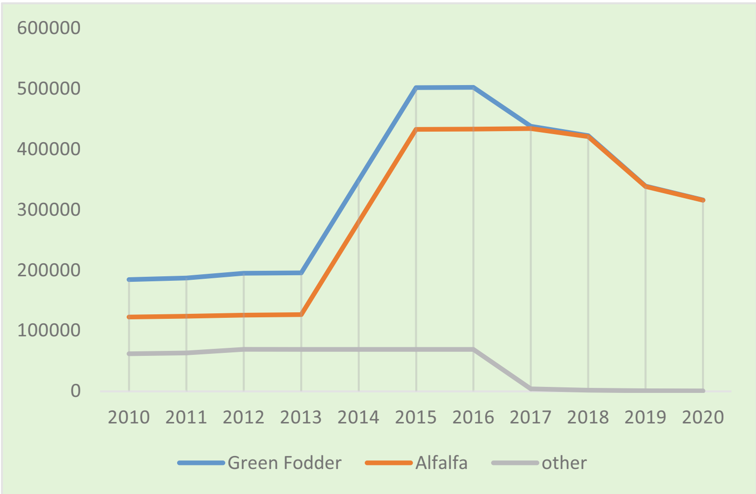


**Fig. 13** Fodder cultivated Area (2010–2020) in ha in Saudi Arabia. *Source* Authors' presentation based on data from General Authority for Statistics, Statistical Yearbook, Various Issues; https://www.stats.gov.sa/en

## 4 Horizontal and Vertical Expansion of Crops Production in KSA

The horizontal expansion in production refers to the increase in the total crop production resulting from the increase in the cultivated area, while the vertical expansion refers to the increase in crop production due to the increase in productivity. Accordingly, it is important to study the change in production into three components. The first is the change in production that attribute to the change in cultivated areas only. The second is the changes that attribute to the change in productivity only. The third component is the change in production arising from the interaction between the effects of area and productivity that influence the level of technical efficiency. According to Siam and Abdelradi (2012), to determine the effects of fragmentation the function below was used (Siam and Abdelradi 2012).

$$(Y_t - Y_0)/Y_0 = \{(Y_t(A_t - A_0))/Y_0\} + \{(Y_t(C_t - C_0))/Y_0\} + \{(Y_t((A_t - A_0)\,(C_t - C_0)))/Y_0\} \quad (1)$$

where:

$Y_t$ = total production of the crop at time t (where t = 1,0)

$A_t$ = the area planted in the crop at time t (where t = 1,0)

$C_t$ = acre yield of the crop at time t (where t = 1,0)

Figure 14 illustrates the effect of the vertical expansion (productivity); horizontal expansion (area) as well as the interaction between them with reference to cereal, vegetables, fruit, and fodder production in KSA during the period 2010–2020 in KSA.

The result revealed that during 2010–2020, cereals increased by (8.82%). This increase in cereals production is attributed to the effect of the vertical and horizontal expansions at rates of about 7% and 1.9%, respectively. It should be noted that the horizontal and vertical increase led to an increase in relative change (area and productivity) by 4.1%. Therefore, to increase cereal production, investments should be directed to increase vertical expansion through the adoption of new agricultural innovations, and increasing non-traditional cultivations in the cereal group with horizontal expansion in sorghum, barley, and millet in Saudi Arabia.

The results revealed that vegetable production decreased by 3.5% which was attributed to a 1.2% and 3% decrease in vegetable productivity and area, respectively, with a relative change of both of them of 3%. Thus more efforts are needed to raise vegetable productivity and increase the area allocated for vegetable production. Contrarily, and in spite of the decrease in fruit areas (3.5) in KSA during the last decade fruit production increased by 13.6% which is attributed to an 11.8% increase in fruit productivity. Both th in fruits vertical and horizontal expansion yields a relative interaction between them amounted to a 2.9% increase in fruit production for the same period in KSA. According to, the KSA government must set an operational

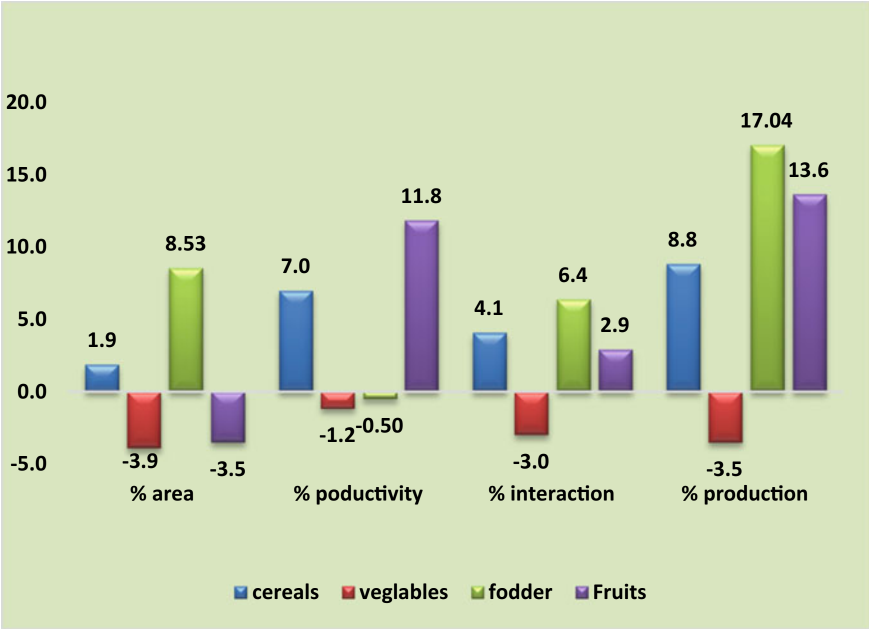


**Fig. 14** The effect of the relative change in area and productivity and the interaction between them during the period (2010–2020) in KSA. *Source* Authors' presentation based on data from General Authority for Statistics, Statistical Yearbook, Various Issues; https://www.stats.gov.sa/en

plan to enhance fruit production, particularly date as it represents the most important export fruit crop for the country. In the same context, during the same period, fodder production increased by 17% attributed to both vertical (0.5%) and horizontal (8.53%) expansions, which produced a relative change between both of them amounting to 6.4%. Hence any future investment will be directed toward vertical expansion as horizontal expansion is constrained by high water requirements for fodder production given water scarcity in KSA so investments can be directed to increase vertical expansion through scientific experiments and non-traditional cultivations in fodder production, especially as the green fodder need more water as Saudi Arabia—Renewable internal freshwater resources per capita decreased during (2010–2020) by rate 35% (World Bank2023).

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# Chapter 5
# Agricultural Trade Performance and Food Security in Saudi Arabia

**Imad Eldin Abdel Karim Yousif**

**Abstract** Saudi Arabia relies heavily on food imports because of a lack of adequate agricultural resources. This study examines the connection between agricultural trade performance and food security in the country. The analysis of trade performance shows a significant positive difference between the period after Saudi Arabia joined the WTO and the period before, in terms, of the value of exports and imports, as well as their share in the GDP. The country's overall trade share in the world market has also expanded since joining the WTO. The measured overall openness index indicates an improvement in the country's integration in the world market following its accession to the WTO. However, the total export growth decreased during the second period after joining the WTO, while total import growth increased. This decline in export growth was mainly due to a sharp decrease in oil prices. As for agricultural trade, the share of agricultural exports in total exports decreased after joining the WTO, although the value of both agricultural exports and imports increased. Saudi Arabia remains a net importer of food products, and this situation has worsened since joining the WTO. The comparative advantage of the agricultural sector has deteriorated more after the WTO accession, but this is mainly due to other factors, such as a shortage of underground water and changes in agricultural policy, rather than the accession to the WTO.

**Keywords** Agricultural trade · WTO accession · Food security · Saudi Arabia

I. E. A. K. Yousif (✉)
Department of Agricultural Economics, College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia
e-mail: imyousif@ksu.edu.sa

Department of Agricultural Economics, Faculty of Agriculture, University of Khartoum, Khartoum, Sudan

 
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## 1 Introduction

Since 2018, food insecurity has been increasing due to rising of frequency of climate shocks, regional conflicts and the pandemic that lead to interruption of food production and distribution, and surging the cost of food and living standards (Georgieva et al. 2022).

International trade in agricultural products can contribute to food security and healthier diets for all countries, especially Saudi Arabia, due to the small share of locally produced food in their total food consumption. International trade connects regions with limited agricultural resources with regions that have comparative advantage in agricultural production and, therefore, the consumers have access to a diversified food basket which helped in reducing food insecurity (Bouet and Laborde 2017). Reducing trade barriers enhances the accessibility to food and reduces food prices. Accession to the World Trade Organization (WTO) is a driver for economic growth and the realization of food security (Smith and Glauber 2020). This chapter analyzes Saudi Arabia's agricultural trade performance before and after its accession to the WTO and its impact on food security.

The economy of Saudi Arabia is the largest in the Middle East and has recently become a member of the G20 group. Traditionally, the main source of income from abroad for Saudi Arabia has been oil exports, which poses a significant risk to the economy as it relies on a single fluctuating commodity. The fluctuation of oil prices over the past few years has highlighted the need for financial sector reform to encourage economic diversification in economies that rely on oil exports (Husain et al. 2015). In this regard, the Saudi Government approved a strategic plan in 2016 called Saudi Vision 2030, which aims to diversify sources of income rather than relying solely on oil exports (KPMG 2018).

As a leading oil exporter, Saudi Arabia became a member of the WTO in 2005 and is a founding member of both OPEC and GCC. Additionally, it is part of the Free Trade Agreement (FTA) with the European Free-Trade Association and the Greater Arab Free Trade Area (GAFTA). These trade agreements are all linked to a strategy of diversifying the economy and facilitating foreign direct investment in the country, as noted by Yousif and Sultan (2018).

Saudi Arabia possesses distinct differences from other countries in terms of natural resource endowment, socio-cultural characteristics, agriculture, industrial and technological bases, and the educational and skill levels of its national workforce, as noted by Rao (2007). Saudi Arabia's accession to the WTO is predicted to restructure and reorganize its national economy, specifically within the production and service sectors, and is expected to stimulate the private sector, as observed by Ramdi and Mansour (2006). The integration of Saudi Arabia's market within the international trade market will increase foreign capital inflows, boost management and competition, and enhance information flows while promoting transparency and accountability within the domestic market (Yousif et al. 2020), Although a study of the economic implications of Saudi Arabia's membership in the WTO indicates that its trade regime has remained unchanged in some areas, modifications have occurred in others, resulting in a marked increase in the share of trade that has had a strong impact on economic activities (Fayq 2017).

## 2 Economic Performance of Saudi Arabia

Analyzing the performance and growth of a country's Gross Domestic Product (GDP) provides a foundation for the mobilization of economic resources to improve the standard of living for its citizens. Figure 1 illustrates the GDP performance of Saudi Arabia from 2011 to 2021. On average, Saudi Arabia's GDP amounted to SR 2.4 trillion. There was a 64% increase in GDP during the period of 2011–2021 as it rose from SR 1.9 trillion in 2011 to SR 3.3 trillion in 2021, mainly due to growing oil exports and prices. However, the growth rate of GDP declined significantly during the years 2014–2017, caused by drops in oil prices, and in 2020 due to the COVID-19 pandemic. In 2021, the GDP growth rate recovered and registered an 18% increase.

The components of GDP are primarily driven by crude oil, natural gas, and the manufacturing sector, which contributed almost 40% to the GDP during the period of 2011–2021. However, in recent years their share has dropped to 24% as shown in Table 1. The agricultural sector has a small share of only 2.4% on average. Other sectors, such as government services, have an average share of 14% of GDP, while wholesale and retail trade make up about 9%.

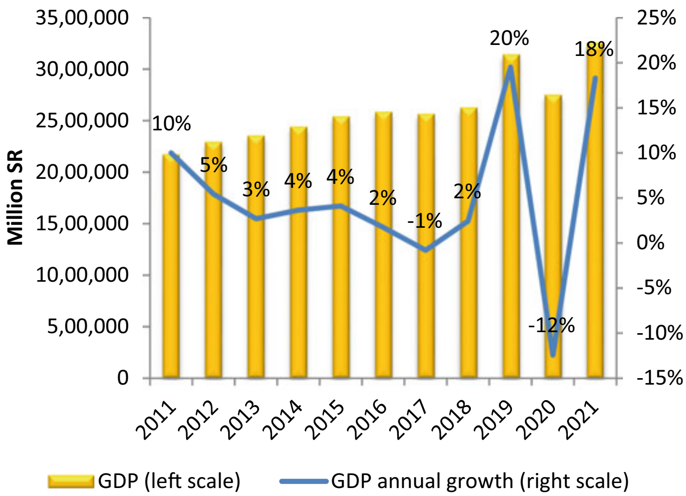


**Fig. 1** Performance of GDP at constant price (2011 = 100), 2011–2021. *Source* General Authority for Statistics-Saudi Arabia

**Table 1** Percentage contribution of economic sectors to Saudi GDP at constant prices, 2011–2021

| | Crude oil and gas | Agriculture | Manufacturing | Wholesale and retail trade | Government services | Others |
|---|---|---|---|---|---|---|
| 2011 | 43 | 3 | 11 | 9 | 14 | 22 |
| 2012 | 43 | 2 | 11 | 9 | 14 | 22 |
| 2013 | 41 | 2 | 11 | 9 | 14 | 23 |
| 2014 | 40 | 2 | 11 | 9 | 14 | 23 |
| 2015 | 40 | 2 | 12 | 9 | 14 | 23 |
| 2016 | 40 | 2 | 12 | 9 | 14 | 23 |
| 2017 | 39 | 2 | 12 | 9 | 14 | 23 |
| 2018 | 40 | 2 | 12 | 9 | 14 | 23 |
| 2019 | 27 | 3 | 13 | 10 | 19 | 30 |
| 2020 | 19 | 3 | 13 | 10 | 21 | 34 |
| 2021 | 25 | 3 | 14 | 10 | 18 | 32 |

*Source* Compiled by the author from data obtained from General Authority for Statistics (2022)

## 3 Saudi Arabia Trade Performance and Food Security

Generally, there is a strong link between trade development and economic growth and development in countries (ITC 2017). Table 2 shows the performance of exports and imports of Saudi Arabia in two periods: from 1995 to 2005, the period before accession to the WTO, and from 2006 to 2021, the period after accession to the WTO. The total export value for the first period amounted, on average, to SR 301 billion with a 21% share in the GDP, while for the second period, it registered, on average, SR 1026 billion with an increasing share in the GDP of 32% (Fig. 2). On the import side, the total import value counted, on average, SR 132 billion with a 9% share in the GDP in the first period, and SR 368 billion and 20% share in the GDP in the second period (Fig. 3). Saudi Arabia mainly exports oil products, in addition to other products. The share of non-oil products in the total export value is 11.4% and 12%, respectively, for the first and second period (Fig. 4). The ratio of the total exports to total imports is greater than one for all periods, reflecting the strong economic situation of Saudi Arabia and its ability to finance imports of goods and services, including food imports. From the above results, it is clear that the accession of Saudi Arabia to the WTO has a positive impact on the trade of goods and services.

**Table 2** Total export and import performance for two periods (Million SR)

| Years | Total exports | GDP share (%) | Total imports | GDP share (%) | Export/Import ratio |
|---|---|---|---|---|---|
| 1995 | 187,403 | 14 | 105,200 | 8 | 2 |
| 1996 | 227,428 | 17 | 102,900 | 8 | 2 |
| 1997 | 227,443 | 17 | 107,600 | 8 | 2 |
| 1998 | 145,388 | 10 | 112,400 | 8 | 1 |
| 1999 | 190,084 | 14 | 104,900 | 8 | 2 |
| 2000 | 290,553 | 20 | 113,200 | 8 | 3 |
| 2001 | 290,553 | 21 | 116,900 | 8 | 2 |
| 2002 | 254,898 | 19 | 121,100 | 9 | 2 |
| 2003 | 349,664 | 23 | 156,300 | 10 | 2 |
| 2004 | 472,491 | 29 | 177,600 | 11 | 3 |
| 2005 | 677,144 | 39 | 222,900 | 13 | 3 |
| Average | 301,186 | 21 | 131,000 | 9 | 2 |
| 2006 | 791,339 | 45 | 261,400 | 15 | 3 |
| 2007 | 874,403 | 48 | 338,100 | 19 | 3 |
| 2008 | 1,175,482 | 61 | 431,700 | 22 | 3 |
| 2009 | 721,109 | 38 | 358,300 | 19 | 2 |
| 2010 | 941,785 | 48 | 400,700 | 20 | 2 |
| 2011 | 1,367,620 | 63 | 493,400 | 23 | 3 |
| 2012 | 1,456,502 | 63 | 583,500 | 25 | 2 |
| 2013 | 1,409,523 | 60 | 630,600 | 27 | 2 |
| 2014 | 1,284,122 | 53 | 651,900 | 27 | 2 |
| 2015 | 763,313 | 30 | 650,200 | 26 | 1 |
| 2016 | 688,423 | 27 | 539,200 | 21 | 1 |
| 2017 | 831,881 | 32 | 541,000 | 21 | 2 |
| 2018 | 1,103,900 | 42 | 513,992 | 19 | 2 |
| 2019 | 981,012 | 31 | 574,361 | 18 | 2 |
| 2020 | 651,952 | 24 | 517,490 | 19 | 1 |
| 2021 | 1,047,650 | 32 | 579,612 | 18 | 2 |
| Average | 1,005,626 | 32 | 504,090 | 21 | 3 |

*Source* General Authority for Statistics-Saudi Arabia

### *3.1 The Growth and Global Market Share of Saudi Arabia's Trade*

Figure 5 shows the growth in the value of exports and imports for Saudi Arabia. Total exports and imports increased by 15% and 7%, respectively, during the period of 1995–2005. After accession, there was a growth of 7% and 9% for exports and

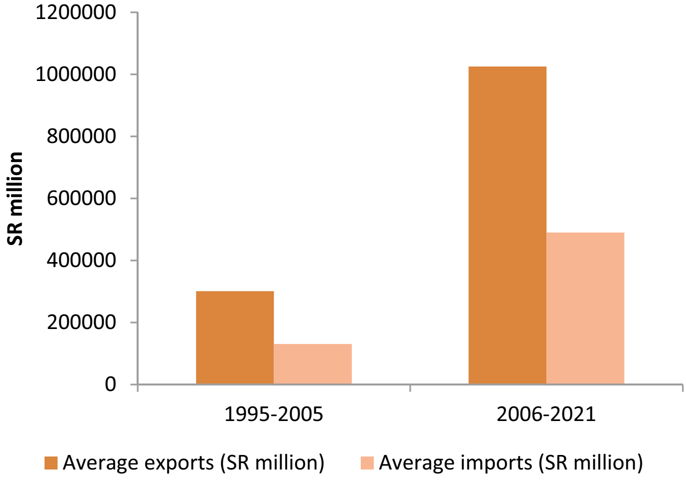


**Fig. 2** Export and imports of Saudi Arabia (1995–2021)

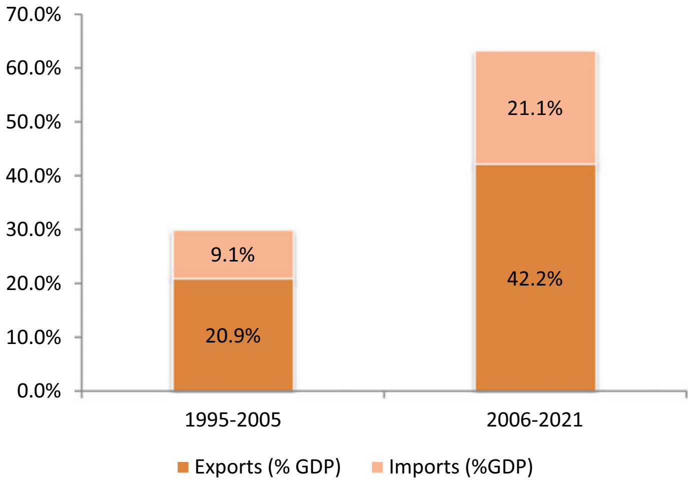


**Fig. 3** Exports and imports share in the GDP (1995–2021)

imports, respectively. The growth in imports increased after accession, while the growth in exports declined due to falling oil prices and the COVID-19 pandemic.

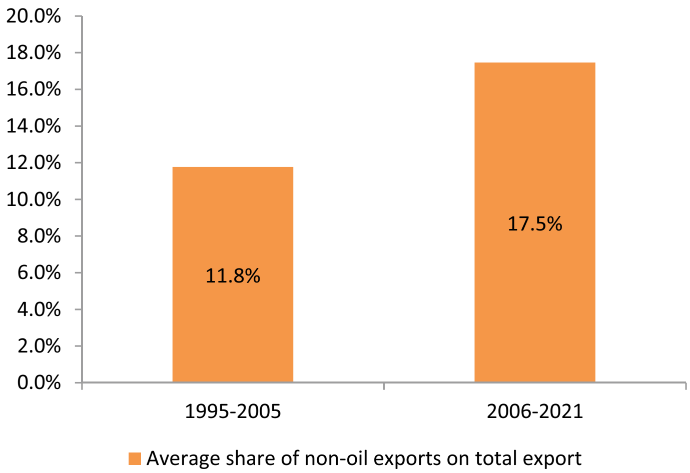


**Fig. 4** Non-oil exports share in total exports (1995–2021)

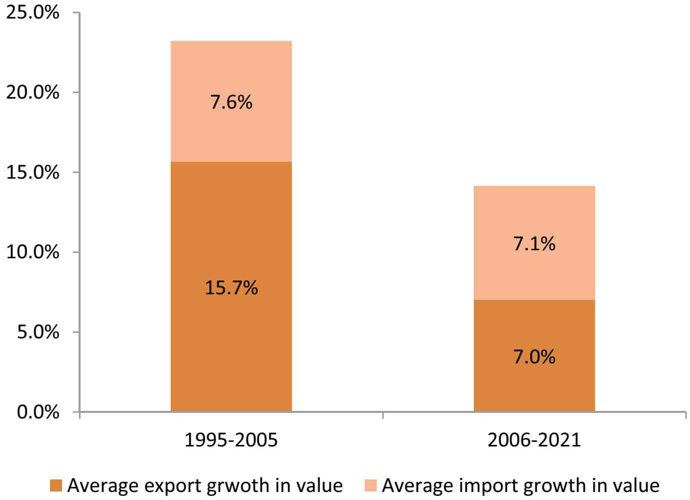


**Fig. 5** Growths in export and import value (1995–2021)

## *3.2 Relative Trade Balance of Saudi Arabia*

The relative trade balance is a ratio that compares a country's trade balance (exports minus imports) to its total trade (exports plus imports). Using this ratio has several advantages, including eliminating the bias towards re-exports, and considering the impact of globalization on production processes (i.e. including imported intermediate goods). The relative trade balance indicates whether a country is a net exporter

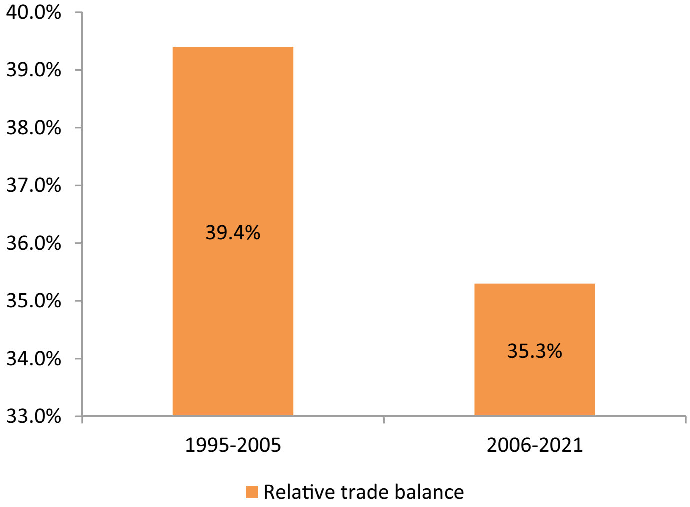


**Fig. 6** Saudi Arabia's relative trade balance (1995–2021)

(producing more than it consumes) or a net importer. This ratio ranges between − 100% and + 100%, where a positive value signifies a net exporter and a negative value indicates a net importer. Figure 6 displays the relative trade balance of Saudi Arabia both before and after its accession to the WTO. The results reveal that Saudi Arabia is a net exporter; however, the ratio fell from 39 to 35% after accession.

## *3.3 Economy Trade Openness*

Trade openness is a measurement of a country's level of integration in the global market. Trade openness has been recognized by several countries as a mean to ensure adequate food security levels (Sun and Zhang 2021).

The openness index for Saudi Arabia is determined through the use of Eq. (1), which is as follows:

$$O = (X + M)/Y \tag{1}$$

where O stands for overall openness, X represents total exports, M represents total imports, and Y represents GDP. A higher value for O reflects greater openness, while a lower value indicates the opposite. The results from the openness index demonstrated that Saudi Arabia's accession to the WTO resulted in stronger integration within the global market. Specifically, the index increased from 0.3 in the first period to 0.7 in the second period (as depicted in Fig. 7). Such openness and integration fostered increased competition in trade and improved food security in Saudi Arabia.

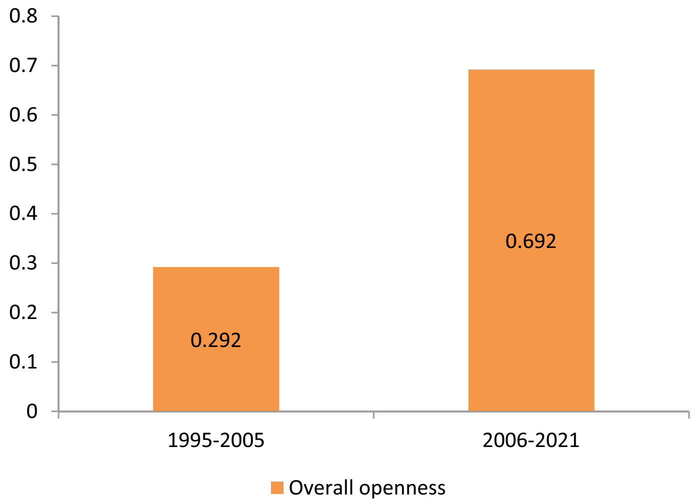


**Fig. 7** Openness index of Saudi Arabia (1995–2021)

## 4 Agricultural Trade and Food Security of Saudi Arabia

The proportion of agricultural trade within total trade is relatively low in Saudi Arabia, mainly due to the lack of potential for agricultural production within the country itself, resulting in a dependence on the world market. Saudi Arabia mainly exports goods such as dates, dairy products, eggs, fish, poultry, fruits, vegetables, and flowers (MEWA 2019). The share of agricultural exports accounts for only 0.74% of total exports and 6.47% of non-oil exports during the first period, and 0.75 and 3.7% in the second period (Table 3). There is no significant variation between the two periods, with the exception of the share in non-oil exports. The value of agricultural exports has increased from SR 2226 million to SR 6412 million after accession, however. On the other hand, the share of agricultural imports is 15.9% and 14.6% for the two periods, respectively (Table 3). Although the share of agricultural imports has slightly decreased after accession, the value of agricultural import also improved from SR 20.5 billion to SR 73 billion after accession, indicating increased integration into the world market. Saudi Arabia's dependence on the world market for food supply puts its food security at risk, making it vulnerable to market fluctuations and shocks. The ratio of agricultural exports to agricultural imports is less than one, meaning that Saudi Arabia's food export revenue is lower than its food imports expenses.

**Table 3** Agricultural trade and food security of Saudi Arabia (1995–2021)

| Years | Exports of agricultural products (in millions SR) | % of share in non-oil exports | % share of total exports | Imports of agricultural products (in millions SR) | % share of total imports | Agricultural export/ agricultural import |
|---|---|---|---|---|---|---|
| 1995 | 1449 | 6.0 | 0.77 | 17,200 | 16.3 | 0.08 |
| 1996 | 1481 | 6.1 | 0.65 | 17,900 | 17.4 | 0.08 |
| 1997 | 1778 | 6.43 | 0.78 | 18,700 | 17.4 | 0.10 |
| 1998 | 1754 | 7.49 | 1.21 | 17,200 | 15.3 | 0.10 |
| 1999 | 1886 | 8.63 | 0.99 | 17,300 | 16.5 | 0.11 |
| 2000 | 1700 | 6.85 | 0.59 | 19,800 | 17.5 | 0.09 |
| 2001 | 1541 | 5.02 | 0.53 | 17,100 | 14.6 | 0.09 |
| 2002 | 1845 | 5.69 | 0.72 | 18,900 | 15.6 | 0.10 |
| 2003 | 3038 | 7.47 | 0.87 | 24,400 | 15.6 | 0.12 |
| 2004 | 3657 | 6.39 | 0.77 | 26,100 | 14.7 | 0.14 |
| 2005 | 4361 | 6.12 | 0.64 | 31,100 | 14.0 | 0.14 |
| Average | 2226 | 6.47 | 0.74 | 20,518 | 15.9 | 0.11 |
| 2006 | 5228 | 6.11 | 0.66 | 33,500 | 12.8 | 0.16 |
| 2007 | 7442 | 7.12 | 0.85 | 42,100 | 12.5 | 0.18 |
| 2008 | 8875 | 7.30 | 0.76 | 58,300 | 13.5 | 0.15 |
| 2009 | 10,159 | 9.27 | 1.41 | 49,800 | 13.9 | 0.20 |
| 2010 | 10,912 | 8.11 | 1.16 | 59,000 | 14.7 | 0.18 |
| 2011 | 12,057 | 6.83 | 0.88 | 68,600 | 13.9 | 0.18 |
| 2012 | 12,380 | 6.48 | 0.85 | 73,900 | 12.7 | 0.17 |
| 2013 | 1967 | 0.97 | 0.14 | 80,500 | 12.8 | 0.02 |
| 2014 | 2340 | 1.08 | 0.18 | 80,900 | 12.4 | 0.03 |
| 2015 | 1880 | 0.99 | 0.25 | 92,500 | 14.2 | 0.02 |
| 2016 | 1773 | 1.00 | 0.26 | 87,200 | 16.2 | 0.02 |
| 2017 | 1939 | 1.00 | 0.23 | 86,100 | 15.9 | 0.02 |
| 2018 | 10,579 | 5.19 | 0.96 | 88,600 | 17.2 | 0.12 |
| 2019 | 10,514 | 5.61 | 1.07 | 91,100 | 15.9 | 0.12 |
| 2020 | 10,360 | 6.13 | 1.59 | 88,400 | 17.1 | 0.12 |
| 2021 | 12,023 | 5.19 | 1.15 | 95,600 | 16.5 | 0.13 |
| Average | 7526 | 3.69 | 0.75 | 73,506 | 14.6 | 0.10 |

*Source* General Authority for Statistics-Saudi Arabia

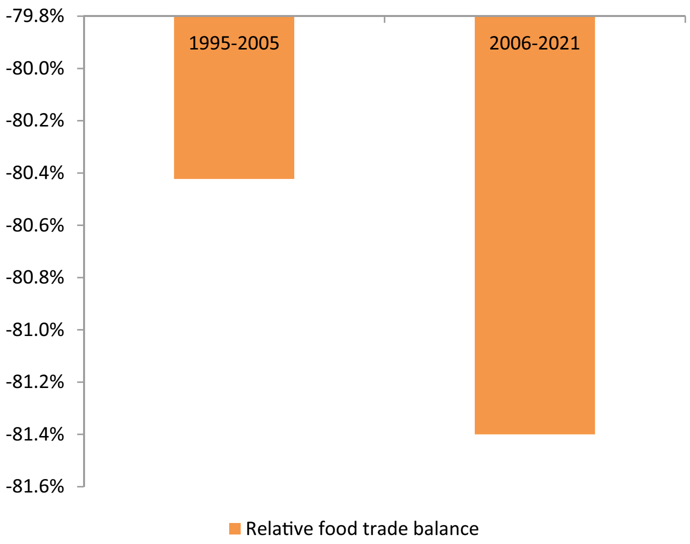


**Fig. 8** Saudi Arabia's relative food trade balance

## 4.1 Relative Food Trade Balance

The trade balance in food for Saudi Arabia is negative both before and after joining the WTO, confirming that Saudi Arabia imports more food than it exports (Fig. 8).

## 4.2 Revealed Comparative Advantage of Agricultural Sector

The Revealed Comparative Advantage (RCA) index, which was introduced by Balassa (1995), is used to measure the development of the agricultural sector's comparative advantage before and after Saudi Arabia joined the World Trade Organization (WTO). The RCA index is obtained by calculating the ratio of the share of product K's exports from country i to its share in the global market. This equation can be expressed as follows:

$$RCA_k^i = \frac{X_k^i}{X^i} / \frac{X_K}{X} \tag{2}$$

where $X_k^i$ is country, its exports consist of good K (which refers to agricultural products). $X^i$ represents the total exports of this particular country, while $X_K$ refers to the world exports of good K, and X is the total world export. If the RCA value for a particular sector or good (here referring to K) is greater than one for a specific

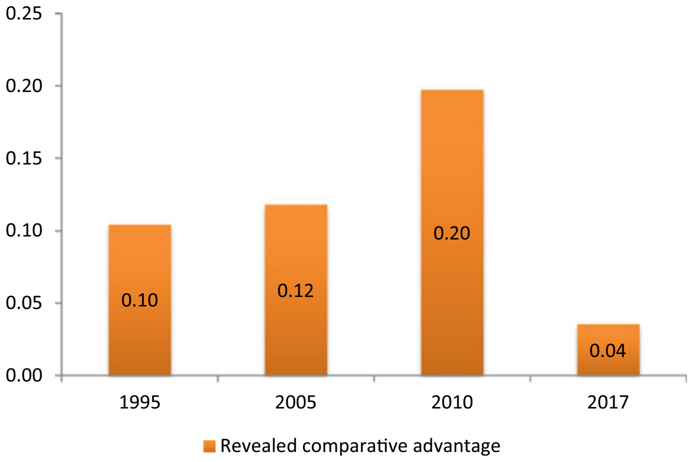


**Fig. 9** The comparative advantage of the agricultural sector

country (referred to as i), this indicates that this country has a comparative advantage in that specific sector or good.

Figure 9 shows the measured RCA of the agricultural sector in Saudi Arabia for four periods (1995, 2005, 2010, and 2017). There is no comparative advantage in agricultural production in Saudi Arabia, as the RCA indexes for all four periods are less than one. This is due to the lack of abundant agricultural resources, especially water resources. The water problem in Saudi Arabia is severe and has resulted in a change in the country's agricultural policy, with a reduction in agricultural production.

## 5 Conclusion and Prospects

The development of the trade sector in Saudi Arabia is clearly apparent, particularly after the country joined the WTO. The exports of both oil and non-oil products have expanded, resulting in an improvement in food security and living standards. However, since Saudi Arabia relies on imported food products, it is vulnerable to fluctuations and shocks in the global market. The measured openness index indicates that the country has become more integrated into the global market after joining the WTO, but total export growth has decreased while total import growth has increased due to a decline in oil prices. The share of agricultural exports in total exports has decreased, although the value of both agricultural exports and imports has increased. Saudi Arabia does not have a comparative advantage in the production of agricultural goods, which exacerbates the situation. Overall, the food security situation in Saudi Arabia is deemed satisfactory, but also critical.

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# Chapter 6
# The Implications of Agricultural Saudi Arabia Investment Abroad on Food Security

**Ibrahim El-Dukheri**

**Abstract** Investment in agriculture is essential for reducing hunger in all facets of food and nutrition security. The government of Saudi Arabia has sought agricultural investment abroad, as well as encouraged Foreign Direct Investment (FDI) to enhance its food security and reduce dependence on food import from international market which is prone to shocks and irregularities. To promote investment abroad, the government had adopted strategic legal and operational frameworks in support of investment abroad including focused strategies and creative initiatives revolving around "King Abdalla Initiative for Saudi Agricultural Investment Abroad," which has targeted 35 countries for agro-investment, with the aim of producing basic and strategic commodities for food security for both the Kingdom and target countries. Other prominent initiatives are "The Public Investment Fund (PIF) initiative" the Saudi Agricultural and Livestock Investment Company (SALIC)," and "the Saudi Private Sector Joint Venture Initiative." investment strategies or methods in the agriculture industry overseas include technology transfers, joint ventures, and outright purchases of agricultural businesses. While these investments bring economic opportunities and enhance food security for Saudi Arabia, it is essential to address social, environmental, and sustainability considerations to ensure the long-term benefits for all stakeholders involved. Saudi Arabia and its agricultural investment entities should adopt stringent environmental and social safeguards, engage in transparent and inclusive governance practices, and actively collaborate with local stakeholders, governments, and civil society organizations. Collaboration of Saudi Arabia with other countries in investment abroad can help to share knowledge, resources, and technology, leading to more efficient and sustainable agricultural practices. This collaboration fosters research and development initiatives aimed at improving crop varieties, developing climate-resilient farming methods, and finding innovative solutions to agricultural challenges.

**Keywords** Food security · Saudi Arabia · Investment abroad · King Abdalla Initiative for Saudi Agricultural Investment Abroad · Foreign Direct Investment ·

I. El-Dukheri (✉)
Arab Organization for Agricultural Development, Khartoum, Sudan
e-mail: Ibrahim.dukheri@gmail.com

 
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Saudi Arabian General Investment Authority · Public Investment Fund · Free zones · Host country · Stakeholders

## 1 Introduction

The UN Committee on World Food Security in 2003 describes food security as "the condition in which 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 (World Bank (n.d); Gibson (2012)." As that definition shows, there are both nutritional and economic aspects to food security. Food utilization, the physical availability of food, economic and physical access to food, and the stability of these three aspects over time are the four dimensions of food security according to the United Nations Food and Agriculture Organization (FAO). The majority of the world's poorest individuals live in rural areas, and investing in agriculture is seen as the most important and successful method to alleviate poverty there, as stated by the World Bank (2008). Investing in agriculture is considered one of the most effective strategies to combat both poverty and hunger (El-Dukheri et al. 2011). Programs to promote agricultural production that are supported by the private sector can help farmers and governments. Public and private sector investment in farm measures can boost agricultural investment and food commodity production.

In general, agricultural investment is the most essential and successful tool for poverty reduction and food security in rural and urban regions and areas, enhancing labor productivity and influencing commodity supply (Ivanic and Martin 2018; Osabohien et al. 2019).

The majority of the world's poorest people reside in rural regions (World Bank 2008), therefore any increase in agricultural investment would benefit poverty reduction and food/nutrition security, primarily in rural areas. Investing in agriculture decreases poverty and hunger in a variety of ways. Farmers make investments to increase their production (food availability) and revenue (food accessibility). From a societal standpoint, this stimulates demand for various rural goods and services, as well as employment and income for those who offer them, the majority of whom are landless rural people. These advantages spread from hamlet to larger economy and food accessibility will be enhanced for all people. The ability to add more items to meals, such as vegetables, fruit, eggs, and milk, is made possible by cheaper staple foods, which improves nutritional absorption (Bouis and Welch 2010). Furthermore, by reducing the food supply's sensitivity to shocks, agricultural investments may increase stability to food consumption. However, domestic investment of developing nations whether public or private is often not enough and must be complemented by Foreign Direct Investment (FDI) and such shortfall usually known as "investment shortfall." This investment shortfall is quite obvious in the agricultural sector of developing nations, although found in other economic sectors.

## 2 Agricultural Investment and Food Security

### *2.1 General Overview of Agricultural Investment*

Both local and international investors may reap a variety of rewards from agricultural investments, including improved production, more readily available food, the creation of jobs, a decrease in poverty, the transfer of technology, and access to money and markets. These advantages won't always materialise on their own, however. They will depend to a large extent on a wide range of factors including the investment contract, the type of business model, the linkages with smallholders, and the institutional framework in place in the host country (Liu 2014; FAO 2014).

Investments in agriculture and food systems must be made responsibly if we want to advance the realization of the right to enough food, improve food security, and improve nutrition. Large-scale agricultural investments may have a significant impact on the local people's degree of food security depending on how they are implemented (Schoneveld 2011). Medium and small scale agricultural investment expand the production base of a country although production efficiency might comparatively be less than in case of large-scale investment, exception is when novel techniques are deployed.

Despite the growing emphasis on agriculture, many developing nations cannot afford to address the investment shortfall. In sub-Saharan Africa, commercial banks lend less than 10% to agricultural, while micro-finance loans are too small for capital development in agriculture (Da Silva and Mhlanga 2009). International donors are unlikely to help either, since agricultural development support has dropped from 5 to 10% (Hallam 2011). G8 and G20 summits have pledged to boost food security investment in developing nation's agriculture.

After decades of underinvestment, most developing countries' agricultural sectors saw a late 2000s FDI surge. This surge was caused by the 2007–2008 commodity price spike and the realization that demand for scarce natural resources is expected to rise rapidly in the next decades. Countries that import a lot of food have invested in countries with plenty of land and natural resources (particularly water) in response to rising food prices. It is widely conceived that domestic food exports and production autonomy provide a more secure food supply than relying on global markets. High energy costs have stimulated worldwide investment in the development of feedstock crops for biofuels. The tendency may continue over the medium to long term according to other factors that are unrelated to the status of the markets at the moment. This rise in agricultural prices is a result of many reasons, including market demand for food, biofuels, raw materials, and carbon sequestration as well as predicted cost increases (Liu 2014).

## 2.2 Importance of Foreign Direct Investment (FDI)

Foreign direct investment (FDI), whether it is inflowing or outflowing, continues to be extremely important for filling the gap in investments, particularly considering the limited support from other countries. It is unlikely that the international assistance will be able to meet the investment demands in the near and medium-term due to the worsening economic crisis in major industrialized nations and the slowing growth in significant emerging economies. This is likely to have negative repercussion on the already precarious food security situation across the globe. To enhance food security, agricultural investment is essential and FDI plays a catalytic role in agricultural investment which quite linked with food security. Investment in agriculture boosts food supply and production, which in turns enhances food security.

Investment in general and FDI in particular is about intensification for productivity enhancement. Crop and livestock production systems must become more productive or even more intensive to meet growing demand but they must also become more resilient and sustainable (FAO 2011). Sustainable intensive production systems are capital-intensive; they require more physical, human, intellectual and social capital in order to sustain and rebuild the natural capital embodied in land and water resources. Net investments of at least USD 83 billion annually are needed in agriculture to meet targets for reducing poverty and ensuring food security (Schmidhuber et al. 2009). Higher crop yields and more environmental friendly farming methods may result from investments in a variety of investment arrangements including investment abroad and/or local investment from country's own capital or through FDI.

## 2.3 Foreign Direct Investment (FDI) Versus Foreign Portfolio Investment (FPI)

There are two commonly used methods for investing overseas: foreign direct investment (FDI) and foreign portfolio investment (FPI). FDI is usually considered a strategic investment as it allows the investor to make a long-term commitment or show an interest in the company and gain access to the local market. On the other hand, FPI is influenced by short-term market fluctuations, with investors buying and selling stocks depending on market conditions. Here are the key distinctions between FDI and FPI:

FDI entails a long term commitment to establishing a business stake in a foreign country. The investor gains control over a foreign company by buying at least 10% of its shares. This is usually a strategic investment as it grants the investor a long-term stake in the company and provides access to the local market. The success of this investment depends on the performance of the local economy. More time-consuming and costly than portfolio investment. A short-term investment strategy called foreign portfolio investment (FPI) is designed to diversify investment portfolios and support the development of foreign economies. It alludes to foreign investors buying securities and other financial assets. The investor does not have any influence over the business entity in which the investment is made.

For a number of economic and non-economic purposes (Post et al. 2021), the most significant of which are import substitution and export promotion, several governments have actively sought out foreign investment and supported Foreign Direct Investment (FDI). Countries have built favorable investment climate to encourage and promote either one or both types, FDI and FPI. Countries have invested much in revisiting and adjusting both the legislative and operational frameworks controlling investment environment in order to create a favorable climate. Critical concerns of institutional realignment are often explored and revisited in order to achieve openness, accountability, and good governance.

## 2.4 Common Measures to Promote Investments

Governments adopt various measures to encourage investment whether in country or abroad, mainly through creating conducive investment environment. This requires a good investment law and creative economic frameworks that facilitate business transactions with inclusive financial setup. In essence, there are many ways to create a conducive environment.

One approach to encourage investment is creation of special zones with its own regulatory frameworks, rules, and regulations, examples of which are shown below:

A government-designated investment zone is a location that promotes investment and economic development in a certain region or industry sector. Investment zones may offer tax rebates, accelerated regulatory procedures, and other benefits to lure businesses to move their operations there.

A free zone is a particular kind of investment zone intended to promote global commerce and investment. It is sometimes referred to as a free trade zone or an export processing zone. Free zones frequently offer businesses that operate within them distinct benefits, such as tax deductions, exemptions from customs requirements, and streamlined regulatory procedures. These zones are commonly situated near ports, airports, or other major transportation hubs in order to facilitate the movement of goods and services across international borders.

Any area that has been designated to promote investment and economic development might be referred to as an economic zone in general. Investment zones, free zones, or other sorts of defined regions may be included in economic zones. Governments at national, regional, or municipal levels can create economic zones, which may provide a variety of incentives and advantages to firms, such as tax cuts, subsidies, or faster regulatory processes.

In conclusion, free zones are concentrated on promoting international trade and investment, while economic zones are a broader term that can encompass various types of designated areas meant to promote economic development and investment.

Investment zones typically aim to promote investment and economic development in a specific region or sector (Alamri and Al-Duwais 2019; Liu 2014; FAO 2014).

## 2.5 Saudi Perspective with Respect to Investment and FDI

Data on inflow and outflow of FDI is limited, but in the second quarter of 2022, Saudi Arabia saw an 85% year-over-year decline in FDI inflows (Reuters 2022). Net FDI outflows from Saudi Arabia as a percentage of GDP were 2.86% in 2021 (World Bank 2023a, 2023b). Saudi Arabia's FDI net flows data, which is accessible from March 2006 through December 2022, is updated quarterly (Bloomberg 2022). Saudi Arabia's foreign direct investment climbed by USD 1.9 billion in December 2022 compared to USD 1.9 billion the previous quarter. The data peaked at 13.8 USD billion in June 2021 and hit a record low of USD 263.7 million in December 2017 (Lippman 2010).

The Saudi Arabian government owns the Public Investment Fund (PIF), which is a sovereign wealth fund. The PIF was established in 1971 with the aim of providing funds for initiatives that promote the development of the nation. To lessen Saudi Arabia's reliance on oil, the PIF has grown in scope throughout time and now oversees the management and investment of public money.

As of 2021, the PIF was one of the largest sovereign wealth funds in the world, with about USD 430 billion in assets under management (AUM. It has made investments in various industries, such as finance, healthcare, energy, infrastructure, and technology. The fund has invested $45 billion in the SoftBank Vision Fund and 5.7% of Tesla, among other prominent overseas investments.

The Public Investment Fund (PIF) has played a leading role in the Saudi Arabian government's efforts to modernize the economy and reduce its dependence on oil revenues in recent years. The main goal of the fund is to invest capital in industries that have the potential to enhance economic growth and create job opportunities. This involves funding start-up tech firms, creating new cities, and supporting renewable energy initiatives. To increase its food security and reduce its dependency on imports, Saudi Arabia has invested a significant amount of money in agricultural projects in other nations during the last several years. In 2022, the Crown Prince of Saudi Arabia, CEO of Public Investment Fund (PIF) launched establishment of five regional companies to focus on five countries; Jordan, Bahrain, Sultanate of Oman, Sudan and Iraq with a portfolio amounting to ninety billion SR (24 billion Dollar).

The Agricultural Development Fund loans have increased by 300% since 2016 to be worth more than 3.7 billion riyals towards the end of 2021. The investment portfolio of the Agricultural Development Fund abroad covers projects that produce eight basic crops, including barley, wheat, corn, oilseeds, and soybeans from Ukraine, in addition to other projects for food security. The fund has started to provide $75 million to Saudi projects abroad, provided that at least 50% of the project's output is exported to the Kingdom. The Saudi Arabian General Investment Authority (SAGIA), previously known as the Ministry of Investment of Saudi Arabia (MISA), oversees and controls foreign investment in the Kingdom, grants permit to potential investors, and seeks to cultivate and promote investment possibilities across the economy.

SAGIA reported in 2020 that the agriculture industry of the Kingdom had spent over SAR 17 billion (USD 4.5 billion), (U.S. Department of States 2022), (HG.org Legal Resources 2023) and in international projects in more than 16 different nations, (Saudi National Portal 2023). These investments have focused on acquiring farmland and investing in livestock, crop production, and food processing facilities.

To help the firms and organizations functioning in the Kingdom and provide them the chance to extend their enterprises overseas and accomplish their goals, the Saudi private sector wants to look into investment prospects in the agriculture sector in 10 Arab nations, including Saudi Arabia.

Saudi Arabia aims to significantly invest in its food and agricultural industries in order to boost domestic production and increase exports of essential commodities like wheat, dates, dairy products, meats, and vegetables to major global markets Saudi Arabia is making headway towards achieving its goal of achieving food security by increasing domestic production and exports of essential foods such as wheat, dates, dairy products, meats, and vegetables; investing in innovation; making long-term investments in countries that have agricultural capacity and a surplus of agricultural exports; the Saudi Agricultural and Livestock Investment Co. (SALIC), which is a corporation owned by the Public Investment Fund (PIF), is playing an important part in this regard.

A rising food manufacturing and processing sector is also present in the country. By the year 2030, it is expected that overall investments in the industry would amount to USD70 billion, an increase of almost 59% from total investments in 2016. To encourage greater foreign direct investment, rules and regulations regulating foreign investment must be flexible.

In February of 2023, the country's sovereign wealth fund expanded its food security initiatives by channelling funding to various food producers, including farmers, livestock owners, and novel interventions like greenhouse projects and conducive financial support initiatives.

Here are some examples of other nations' foreign agricultural investment programs:

- China: Chinese policymakers have ambitious strategic objectives for agricultural investments in order to restructure agricultural trade patterns and expand China's influence in global markets. Foreign investment in agriculture and food industries is part of a larger push to encourage Chinese enterprises to become economically competitive by entering worldwide markets.
- Indonesia, Malaysia, Laos, Pakistan, and Kazakhstan: These nations are being targeted for international agricultural investment.
- Africa: Many African nations, notably Sudan, Ethiopia, and Mauritania, are attracting international agricultural investment.
- Saudi Arabia: Saudi Arabia has substantially engaged in food production internationally, spending billions of dollars buying or leasing enormous areas of land all over the world.

Foreign agricultural investment programs vary by nation and strive to achieve various aims such as maintaining food security, enhancing economic competitiveness, and influencing agricultural trade patterns.

## 3 The Legal and Operational Framework for Saudi Investment Abroad

Saudi investment abroad is based on the Foreign Investment Law (FIL) and its rules, as well as many bilateral and multilateral investment agreements.

Saudi and foreign investments are governed by the 2000 FIL. It describes foreign investors' rights and responsibilities in starting and running foreign-owned firms. The law covers various investment-related operations, including joint ventures, mergers and acquisitions, and portfolio investments.

In addition to the FIL, Saudi Arabia has negotiated several bilateral investment treaties (BITs) and free trade agreements (FTAs) with other nations to protect and incentivize Saudi investors conducting business abroad. These agreements often encompass expropriation, dispute resolution, free money and labor. The World Trade Organization (WTO 2023) and the Organization for Economic Cooperation and Development (OECD 2010), which give further norms and criteria for foreign investment, are two other international organizations that Saudi Arabia collaborate and coordinate with in the course of and supporting trade and investment agenda.

## 4 Saudi Arabia Agricultural Sector and Investment Abroad

### *4.1 Saudi Arabia's Agricultural Landscape*

Although desert conditions make cultivation unlikely, agriculture is an important business in Saudi Arabia (Rahman et al. 2022), from Hail in the north to the lowlands surrounding Taif in the west to the terraced slopes of the southwest, made possible by decades of government subsidies and irrigation facilities with water pumped from subterranean caverns. Agriculture accounted for roughly 5% of GDP and 12% of the workforce in 2008 (Library of Congress 2023).

Saudi agriculture's self-sufficiency in wheat, chicken, figs, grapes, and citrus fruits, and rising olive oil output are celebrated in a documentary on Saudi state television's "This is Our Country" programme. Given the volume of French fries eaten at fast-food outlets, the "Desert Kingdom" generates flowers and potatoes (Lippman 2010). These are all success stories indicating not only capabilities to contribute to food security but also inherent potential of agricultural sector in Saudi Arabia (Middle East Policy Council 2023).

Even with heavy irrigation and advanced agricultural technologies, just 2% of the country's vast land mass is arable, therefore it has traditionally imported food. As the youthful population outgrows output, that reliance is growing. Saudi Arabia's poor land and shrinking water supplies will not be enough to sustain its expected 77% population expansion by 2050. Saudi planning prioritizes "food security" in a world where food competition will only intensify (Lippman 2010).

In spite of achievements made in agricultural sector, challenges are huge. Saudi Arabia's domestic agricultural sector faces significant challenges due to its arid climate, limited arable land, scarcity of water, and dependence on food imports.

Alternative solutions are urgently required to assure food security, sustainability, and less reliance on international markets in light of these obstacles. Saudi Arabia seeks to develop a resilient and self-sufficient agricultural sector capable of meeting the requirements of its expanding population through innovative approaches, investments in technology, and strategic partnerships. Investment abroad remains an amenable option to tackle resource-limitation problem inherent in Saudi agriculture (Hindiyeh et al. 2023).

## *4.2 Food Import as a Pressing Factor for FDI*

Because of its robust fiscal balance and huge oil reserves, Saudi Arabia is able to bring in or import food from other countries to sustainably meet its food requirement, most often in favorable terms.

According to the World Trade Organization, Saudi Arabia imported USD 14.4 billion worth of agricultural products in 2020, while its agricultural exports totaled USD 4.4 billion (Food Export 2023), (Best Food Import 2020; USDA 2023).

The principal agricultural imports of Saudi Arabia include: Cereal valued at USD 3.3 billion in 2020, primarily wheat, maize, and rice. Livestock products valued USD2.9 billion primarily poultry, beef, and lamb. Dairy products valued at USD 2.3 billion, primarily milk, cheese, and yogurt. Fruits and vegetables valued at USD 2.2 billion primarily avocados, pears and tomatoes valued at USD 2.2 billion, primarily avocados, pears, and tomatoes. Sugar valued at USD1.7 billion.

Although the country is capable of meeting its import requirement to ensure its food security, the import bill is so high that it warrants focused and targeted interventions to curb its growth. The import bill is likely to grow steadily or even exponentially as a result of population growth and improvements in income. Alexandratos and Bruinsma (2012) estimate that by 2050, there will be large increases in demand for cereals (45.5%), sugar (74.9%), and meat (76.4%) and countries that are net importers are likely to fall victims for possible supply breakage and shocks and accordingly would and should take precautionary measures.

The food security crisis that occurred in 2008 worldwide caused the Saudi government to have considerable worries over the food security and supply chain sustainability challenges that are present at time in the nation. As a consequence of the food-crisis containment strategies implemented by several key production Hubs, the supply chain was disrupted, and prospective contracts for food commodities were cancelled, which led to a worsening of the country's already precarious situation with respect to food security, at least in supply chain sustainability. This setting has exacerbated the desire and action of the Saudi government to seek alternative means to boost supply side of agricultural goods from both domestic and foreign investment (investment abroad). Specifically, this situation has made it more important to promote supply side of agricultural products [summary and synthesis of The Economist (2022); Mckinesey and Company (2023); World Bank (2022)].

Saudi Arabia has been aggressively investing in food production abroad in an attempt to sustainably meet its demand of agricultural commodities enhance its food security. Prospect of expansion in domestic or own production is constrained by limited agricultural resources, namely suitable land as most of the lands are in desert or desert like conditions. Water scarcity is by and large the most constraining factor limiting expansion in agricultural production in Saudi Arabia.

The Public Investment Fund company "Saudi Agricultural and Livestock Investment Co. (SALIC)" was established in 2009 as a joint stock company owned by the Public Investment Fund (PIF) to contribute to food production and supply through investments in agricultural and livestock businesses around the world as well as in Saudi Arabia. This followed King Abdullah's 2008 launch of the "Initiative for Saudi Agricultural Investment Abroad," which encouraged Saudis to go abroad and buy land.

The King Abdullah Initiative on Agricultural Investments overseas partially encourages these acquisitions by providing subsidies to Saudi enterprises investing in the private sector for agricultural activities in overseas markets. The program, which is part of the Kingdom's food security initiative, aims to diversify and stabilize sources of foreign food supplies.

## *4.3 Rationale and Actions for Agricultural Investments Abroad*

Saudi Arabia's decision to invest in the agricultural sector abroad is motivated by several factors, including:

A. Ensuring Food Security:

As Saudi Arabia is heavily dependent on food imports, investing in local agriculture and farming projects abroad is seen as a way to reduce this dependence and ensure a stable supply of food for the country's population. The King Abdullah Initiative for Saudi Agricultural Investment Abroad aims to contribute to realizing national and international food security.

B. Mitigating Risks Associated with Domestic Production:

The Kingdom of Saudi Arabia's present and future needs to expand domestic production without utilizing desert agriculture are limited by land and water scarcity.

Investing in agriculture and farming projects abroad can help mitigate these risks and diversify the country's sources of food.

C. Accessing New Markets:

Saudi Arabia's investments in domestic and international farming endeavors may potentially open up new markets for the nation's agricultural goods. Companies who cultivate commodities including alfalfa, wheat, barley, sugar, rice, and maize and export at least half of their product to Saudi Arabia are eligible for low-interest loans from the foreign finance.

In general, Saudi Arabia's investments in the agricultural industry overseas are motivated by a desire to guarantee food security, reduce production-related risks, and open up new markets for the nation's agricultural goods. These investments are part of the country's Vision 2030 plan for reforming the Saudi economy and achieving sustainable development (Kingdom of Saudi Arabia 2023, U.S. Department of State 2022; IMF 2023).

The Saudis were hit hard by the 2007 global commodities crisis, exemplified by high prices and supply chain breakage, when India, a primary rice supplier, briefly restricted shipments due to a shortfall and maize and other grain prices skyrocketed. The Saudi government awarded a USD267 per tonne subsidy to stabilize the market for long-grain Basmati rice, only to remove it two years later when it found that exporters benefited more than Saudi consumers. In 2007, Saudi Arabia learnt a lesson when, despite its oil riches, it was unable to buy all the rice it needed. Imports dropped by about 958 thousand causing irregularities in food supply or "food availability" in food security jargon (El-Dukheri et al. 2012).

A similar irregularities happened during Covid-19 where lockdowns across the Globe resulted in serious supply shortage and high food prices causing considerable food insecurity in poor states and marginalized communities. Even rich states had to drain treasuries to maintain good supplies for population at reasonable prices.

Maintaining state food supply sustainably and at reasonable prices remains of prime objectives of governments, either from local production if potential exists or through faire and reasonable trade. International shocks like that of 2008 food crisis or 2019 Covid have proven that trade has increasingly been vulnerable to economic shocks apart of immense environmental shocks caused by climate-change atrocities. states have increasingly relied on investment abroad as a mechanism to counter effect possible supply-chain breakage resulting from unstable trade influenced by various shocks and Saudi Arabia is no exemption, but rather leading in the region and has embarked intensively in investment abroad in agricultural sector to enhance food security and has accordingly taken necessary steps to create necessary and required environment for that.

### 4.4 Performance and Impact of Saudi Investment Abroad

To promote food security, economic diversification, and sustainable development, Saudi Arabia has been funding global agricultural initiatives. The Saudi Agricultural and Livestock Investment Company (SALIC) was founded by the government in 2011 to collaborate with commercial agribusinesses throughout the world to provide goods for the domestic market. SALIC owns agricultural land in supplier countries such as Ukraine, Australia, the EU, and the Americas, and cultivates crops according to Saudi Grains Organization (SAGO) specifications before exporting them to the Kingdom. The Saudi food and agriculture industry's foreign investments range from collaborative partnerships to pioneering ventures, fostering the exchange of agricultural knowledge, technology transfer, and capacity building on a global scale. One of the most fruitful locations for Saudi agricultural investment thus far has been Sudan, where the Kingdom has doubled its investment in the Sudanese agricultural sector in recent history. Investments have surpassed $13bn and constitute 34% of all investment in the local industry, up from 7% as of 2021. The government has also agreed to allocate SR91 billion to raise local content and invest in food products, increase domestic output, and increase export capacity. The Agricultural Development Fund's investment portfolio abroad amounted to one billion riyals, an increase of about 55% over its value in 2019. The first year of the foreign agricultural investment program experienced the approval of loans totaling 644 million Saudi riyals, with the aim of growing and supplying barley, wheat, corn, oilseeds, and soybeans from Ukraine, in addition to approving a project for one of the national companies specialized in agricultural investment and animal production in Sudan.

Saudi Arabia's foreign agricultural investment program covers eight basic crops, which are barley, wheat, corn, oilseeds, soybeans, rice, maize, and fruits. As a part of the Kingdom's attempt to increase food security, the programme seeks to diversify and stabilize the sources of foreign food supply.

The food security of Saudi Arabia has been significantly impacted by the kingdom's foreign agricultural investments. The government's plan to invest in agricultural infrastructure and acreage overseas has given Saudi companies the ability to manage the supply chain and shield the nation from exogenous shocks brought on by sharp increases in commodity prices.

State-owned and private Saudi investors have spent billions of dollars to buy or rent vast tracts of land in a number of nations across the world. They control the production of rice in Ethiopia, Sudan, and the Philippines. They also control the production of cattle in California and Arizona, wheat in Ukraine and Poland, ranches in Argentina and Brazil, and prawns in Mauritania. The King Abdullah Initiative on Agricultural Investments Overseas, which offers financial assistance to private sector investments made by Saudi firms in agricultural operations situated in foreign markets, is one factor that encourages these purchases. Over years, the program has resulted in the signing of forty contracts across thirteen nations, and Saudi investors were enabled to manage and run major farms in the United States of America, the Sudan, Egypt, Argentina, and Ukraine.

Although there is focused and systematic engagement by both public and private sector to expand and mainstream investment abroad as an effective mechanism for achieving food security in the Kingdom, local production has also been supported and shaped up in order to exploit its potential. As of 2021, the government has reached an agreement to set aside SR91 billion in order to boost the proportion of locally produced goods, enhance investment in food items, boost domestic production, and expand export capacity.

The Foreign Agricultural Investment Program that is run by Saudi Arabia is only one of several such programs that are run all over the world. These comparisons are provided:

***Scale:*** Scale: Saudi Arabia has made substantial investments in the international food production sector, spending billions of dollars to buy or lease vast expanses of land in several nations across the globe. Despite this, the figures show that the country's overall agricultural investment is just a relatively small portion of agricultural foreign direct investment (FDI).

***Focus:*** Saudi Arabia's agricultural investments overseas are concentrated on diversifying the sources of food supply from other nations in order to better ensure food security as part of the Kingdom of Saudi Arabia's ongoing food security policy. In comparison, China has broaden agricultural interests in over a hundred different nations, including crop and animal farming, fishing, processing, farm machinery, inputs, seeds, and logistics. China's agricultural investments also include fisheries.

***Impacts:*** Saudi Arabia's agricultural investments overseas have both positive and negative effects on the country's homegrown food supply markets. Among the positive effects are a rise in food security and a decrease in reliance on production inside the country. One of the unfavorable effects is an increase in the cost of food, and another is social strife in areas where local residents are severely affected.

In general, despite the fact that Saudi Arabia's program to invest in overseas agriculture on a major scale is centered on guaranteeing food security, the program is simply one example of the many similar programs that exist a cross the world with various objectives and effects.

The objectives and approaches utilized by various nations' programs designed to encourage foreign direct investment in agriculture can result in a wide range of potential outcomes.

The Government of Saudi Arabia like others as explained earlier has created conducive investment environment by designating investment zones, free zones, and economic zones as places to promote economic growth and draw investment. The King Abdullah Economic City (KAEC), West Jazan, Ras Al Khair, and other special economic zones (SEZs) that have been established around the nation with incentives for foreign businesses to operate within the kingdom, and these are good examples of investment zones in Saudi Arabia. These cities are anticipated to aid the Saudi government's initiatives to diversify its economy by providing fresh opportunities for business growth.

Furthermore, Saudi Arabia is moving forward with its Vision 2030 reform strategy, which intends to boost the private sector's contribution to GDP, from 40 to 65% and also contributes to GNP, primarily through investment abroad by both public and private sector.

## *4.5 Investment Strategies and Initiatives*

In order to fulfill its objectives of maintaining food security, limiting risks connected with local production, and reaching new markets, Saudi Arabia has used a variety of investment strategies or initiatives in the agricultural industry overseas, the most prominent are:

### 4.5.1 Investment Strategies

A. Direct Acquisitions:

Saudi investors have been purchasing or leasing enormous areas of land all over the globe in order to cultivate crops and provide food for themselves and others. For instance, Saudi investors are in charge of rice farms in Ethiopia, Sudan, and the Philippines; cattle ranches in California and Arizona; wheat fields in Ukraine and Poland; ranches in Argentina and Brazil; and prawn producers in Mauritania. These are only a few of the nations where Saudi investors are active.

In order to cultivate and provide barley, wheat, maize, oilseeds, and soybeans in Ukraine, loans totaling 644 million Saudi riyals have been approved by the Saudi Arabian Agricultural Development Fund.

B. Joint Venture:

Saudi Arabia is interested in investigating investment prospects in the agriculture industry in ten Arab nations, including Morocco, Mauritania, Tunisia, Oman, the United Arab Emirates, Egypt, Qatar, and Iraq. This is being done via joint ventures. The Federation of Saudi Chambers offered a complete and exhaustive list of upcoming projects in the specified countries to benefit the companies and institutions operating in the Kingdom and give them the chance to develop their operations overseas and accomplish their objectives. The list was provided for the benefit of the organizations and businesses functioning in the Kingdom. In addition, investors have the opportunity to participate in or contribute to the full exploitation of the production capacity of the Arab Sea Goods Factory in Jeddah, which is located in the western region of the Kingdom.

C. Technology Transfer:

Saudi Arabia has been investing in agricultural technologies and the transfer of agricultural expertise in order to boost crop yields and production efficiency. Saudi businesses are given financial assistance by the King Abdullah Initiative on Agricultural Investments Overseas to encourage them to engage in agricultural activities in foreign markets. This in turn motivates customers to buy things. As a consequence of this endeavor, forty contracts have been signed in thirteen additional countries, with Saudi investors now in charge of massive farms in the United States, Sudan, Egypt, Argentina, Australia, and Ukraine.

In general, Saudi Arabia's investment methods in the agriculture industry overseas include technology transfers, joint ventures, and outright purchases of agricultural businesses. These policies intend to help the government accomplish its objectives of maintaining food security, reducing risks connected with domestic production, and expanding access to new markets for the agricultural products of the country.

### 4.5.2 Investment Initiatives

Saudi Arabia has undertaken a number of focused, well planned and coordinated initiatives to facilitate agricultural investment abroad. The following are most prominent ones implemented by Saudi private sector entities or government agencies:

A. King Abdullah Initiative for Saudi Agricultural Investment Abroad:

This initiative seeks to promote national and international food security by investing in agriculture and agricultural ventures abroad. The Agricultural Development Fund, the initiative's financing arm, declares and announces the terms and conditions for international funding in order to regulate and streamline investment processes.

B. The Public Investment Fund (PIF):

PIF is a sovereign wealth fund run by the Saudi Arabian government. It has made investments in other agricultural projects abroad, including a \$10 billion contribution to SoftBank's Vision Fund, which has backed several agtech companies.

C. Saudi Agricultural and Livestock Investment Company (SALIC) Initiative:

SALIC is a Saudi government-owned corporation that invests abroad in agricultural and livestock initiatives. It has invested in multiple initiatives in countries including Australia, Brazil, Canada, Ukraine, and the United States.

D. Saudi Private Sector Joint Venture Initiative:

The Saudi private sector intends to investigate investment opportunities in the agricultural sector in 10 Arab nations, including Saudi Arabia. The Federation of Saudi Chambers presented an exhaustive and detailed list of future projects in the specified countries to benefit companies and institutions operating in the Kingdom and provide them with the opportunity to expand their businesses abroad and attain their objectives.

The Saudi Arabian government manages the PIF, a sovereign wealth fund. It has contributed to a number of agricultural projects abroad, including a \$10 billion investment in SoftBank's Vision Fund, which has contributed to a number of ag-tech companies.

### 4.6 Targeted Regions and Countries

Implementation strategies and initiatives of investment abroad covered almost most regions of the Globe based on strategic selection of each location as influenced by factors such as arable land availability, water resources, local partnerships, and market potential. Some of the regions and countries where Saudi Arabia has focused its agricultural investments includes (UNCTAD 2011):

**Sudan:** Using its lush terrain and ample water supplies, investment has been concentrated on large-scale agricultural projects. These expenditures have mostly gone towards growing crops like sorghum, maize and wheat.

Southeast Asia:

**Indonesia:** Saudi has established joint ventures and invested in agricultural projects in Indonesia, aiming to benefit from the country's vast arable land and favorable climate. These projects include rice cultivation and palm oil production.

**Malaysia:** Saudi Arabian companies have invested in Malaysia's agriculture industry, notably in the production of livestock and poultry and the development of palm oil.

**Eastern Europe:**

Ukraine: Saudi Arabia has shown interest in Ukraine's agricultural sector due to its extensive arable land and favorable agro-climatic conditions. Investments have been made production of grains, including wheat and corn.

**Latin America:**

Argentina: Drawn by the country's abundant soil and suitability for crop development, Saudi Arabia has made investments in the agricultural sector. Investments have been concentrated on the cultivation of soybeans as well as other commodities like maize and wheat.

**Central Asia:**

Kazakhstan: Saudi Arabia has explored agricultural investments in Kazakhstan, considering its large arable land area and potential for crop cultivation. These investments have primarily targeted production of wheat and other grains.

**Middle East:**

Egypt: Saudi Arabia has invested in agricultural projects in Egypt, capitalizing on its agricultural potential, including the Nile River and fertile lands. Investments have focused on cultivating crops like wheat, corn, and rice.

It's important to note that specific investments and projects may vary over time, and new partnerships and locations may emerge as Saudi Arabia continues to pursue agricultural investment abroad. These investments aim to secure food resources, diversify agricultural production, and strengthen bilateral ties with host countries, while considering factors such as natural resources, local partnerships, and market potential.

## *4.7 Technology Transfer and Knowledge Sharing*

Saudi Arabia's agricultural investments abroad have also played a significant role in facilitating technology transfer and knowledge exchange in the agricultural sector. These investments have not only provided financial resources but have also contributed to the transfer of innovative agricultural technologies, best practices, and expertise. Here are some dimensions of technology transfer and knowledge exchange associated with Saudi Arabian agricultural investments abroad:

A. Advanced Agricultural Techniques:

Saudi Arabian agricultural investments abroad have introduced advanced agricultural techniques and practices to host countries. For effective crop monitoring and management, this involves the use of precision farming technology like remote sensing, geographic information systems (GIS), and drones. These innovations contribute to increased crop yields, resource efficiency, and overall agricultural output.

B. Water Management and Irrigation Systems:

Given Saudi Arabia's expertise in efficient water management in arid regions, their agricultural investments abroad have often focused on sharing knowledge and technologies related to water conservation and irrigation systems. This includes the introduction of modern irrigation techniques such as drip irrigation, sprinkler systems, and precision watering methods. These practices enable the optimal use of water resources, minimizing wastage and maximizing crop yields.

C. Sustainable Farming Practices:

Saudi Arabian investments in foreign agricultural projects have emphasized sustainable farming practices, including organic farming, integrated pest management, and soil conservation techniques. These practices aim to reduce the use of chemical inputs, minimize environmental impact, and promote soil health and biodiversity. By sharing these sustainable farming practices, Saudi Arabia contributes to the adoption of environmentally friendly approaches in host countries.

D. Research and Development Collaboration:

Saudi Arabian agricultural investments abroad often involve partnerships with local research institutions, universities, and agricultural centers. These collaborations foster research and development initiatives aimed at improving crop varieties, developing climate-resilient farming methods, and finding innovative solutions to agricultural challenges. This collaboration promotes knowledge sharing, joint scientific advancements, and technology development for the benefit of both host countries and Saudi Arabia.

E. Training and Capacity Building:

Another dimension of technology transfer and knowledge exchange is the provision of training programs and capacity-building initiatives. Saudi Arabian investments often include educational and vocational programs for local farmers and agricultural workers. These training programs cover various aspects of modern farming techniques, machinery operation, pest management, post-harvest handling, and marketing strategies. Such capacity-building efforts empower local communities, enhance their skills, and contribute to the overall development of the agricultural sector in host countries.

F. Exchange of Expertise:

Saudi Arabian agricultural investments abroad involve the exchange of expertise and knowledge between Saudi agricultural professionals and their counterparts in host countries. This includes agricultural experts, agronomists, researchers, and technicians sharing their experiences, conducting workshops, and offering technical assistance. The exchange of expertise nurtures a cross-cultural learning environment, promoting innovation and fostering long-term collaborations.

These dimensions of technology transfer and knowledge exchange illustrate how Saudi Arabian agricultural investments abroad go beyond financial investments. They contribute to the sustainable development of agricultural sectors in host countries, enhance food production capabilities, and support the mutual growth and advancement of the agricultural industry globally.

Overall, Saudi Arabia's investments in the agricultural sector abroad have led to successful technology transfer initiatives and positive outcomes for both parties. These initiatives have helped to improve crop yield and have contributed to realizing national and international food security agenda.

## *4.8 Economic Impacts of Agricultural Investment Abroad*

Investing in agricultural overseas can have a variety of consequences, both for the investing and host countries. Often times, the focus is on immediate economic benefits or consequences of investment on both host and investing countries.

Host Country: It has the potential to create employment, enhance infrastructure, and boost agricultural output. If the produce is exported, it can help encourage local economic growth and foreign exchange gains. However, if not adequately managed, it might result in the displacement of local farmers or enterprises, thereby increasing economic disparity.

Investing Country: It provides access to new markets, diversifies revenue streams, and may help to guarantee food security if the produce is imported back home, directly contributing to food availability which is an important pillar of food security. Alternatively, if produced commodities of investment abroad are to be sold in the international markets, income benefits or proceeds will enhance accessibility to food commodities—second pillar of food security. Companies or public entities that make such investments benefit from new commercial prospects as well.

Here are some cases of prominent Saudi Arabian agricultural investments in different regions, highlighting the diversity of projects and their impact on both the host countries and Saudi Arabia:

Case of Saudi Agricultural Investment Company (SALIC) in Sudan

SALIC, partnered with the Sudanese government to establish a joint venture called the "Sudanese Saudi Agricultural Investment Company" (SSAIC). The venture aimed to develop large-scale agricultural projects in Sudan, focusing on wheat, corn, and sorghum production.

Impact: The project contributed to Sudan's agricultural sector by introducing modern farming techniques, improving irrigation systems, and enhancing productivity. It also created employment opportunities for local communities and strengthened Sudan-Saudi Arabia economic ties. For Saudi Arabia, the investment helped secure food sources and contributed to country's effort to reduce dependence on food imports.

Case of Saudi Star Agricultural Development in Ethiopia

Saudi Star Agricultural Development, a Saudi company, initiated a major agricultural project in Gambella, Ethiopia. The project involved large-scale rice cultivation, aiming to utilize Ethiopia's fertile land and water resources.

Impact: The investment significantly impacted the local economy by providing employment to thousands of Ethiopians and contributing to infrastructure development in the region. However, the project also faced challenges related to land acquisition, community displacement, and environmental concerns, leading to mixed reactions about its overall impact.

Case of Almarai's Dairy Farms in Argentina

Almarai, a Saudi Arabian food and beverage company, invested in dairy farms in Argentina to secure a consistent supply of animal feed. The project involved acquiring farmland for forage production, primarily alfalfa, to support the company's dairy operations in Saudi Arabia.

Impact: The investment provided Argentina with foreign direct investment (FDI) and expanded opportunities for agricultural exports, as the alfalfa produced in Argentina was exported to Saudi Arabia. It also enhanced agricultural knowledge exchange and technology transfer between the two countries.

Case of Saudi Grains Organization (SAGO)in Ukraine

SAGO, has made significant investments in grain production in Ukraine. The investments focused on cultivating wheat and other grains, utilizing Ukraine's abundant arable land and favorable agro-climatic conditions.

Impact: The investments in Ukraine have strengthened bilateral ties and agricultural cooperation between the two countries. They have also contributed to Ukraine's grain production and export capacity, boosting its agricultural sector and economic growth.

These case studies demonstrate the diverse nature of Saudi Arabian agricultural investments abroad and their impacts on both the host countries and Saudi Arabia. While these investments bring economic opportunities and enhance food security for Saudi Arabia, it is essential to address social, environmental, and sustainability considerations to ensure the long-term benefits for all stakeholders involved.

## 4.9 *Environmental Sustainability and Social Impact of Investment Abroad*

Saudi Arabia investments have faced scrutiny regarding their environmental sustainability and social impact on host countries and Saudi Arabia as well. Both social and environmental consequences occur rather late compared to economic effects: Braun and Meinzen-Dick (2009), working paper 85. The following points depict possible environmental and social effects or consequences.

### 4.9.1 Environmental Sustainability

Host Country: If sustainable techniques are not implemented, large-scale agricultural investments which often dominate agricultural investment abroad can lead to negative environmental consequences, including deforestation, biodiversity loss, and soil and water contamination. Application of sustainable agricultural techniques which should under pine the investment, on the other hand, have the potential to benefit the local ecosystem and reduce negative environmental consequences.

Investing nation: If the investment is motivated by the desire to protect domestic resources, it may result in less strain on environment in home nation. However, there may be backlash if the investment causes environmental damage elsewhere. In general there is a growing concern about environmental consequences in investment, domestically or abroad.

To maximize the advantages and avoid negative repercussions, investing parties must use ethical investment methods. This includes protecting land and water rights, paying fair wages, interacting with local people, employing sustainable agricultural techniques, and being open about their operations. Furthermore, the governments of both investing and host nations should have clear legislation and monitoring in place to guarantee that investment helps local people and economy, as well as ensuring environmental and social protections are in place (FAO 2014).

In Saudi Arabia, environmental consequences can be portrayed in natural resources, mainly water, soil and forest resources as follows:

*Water resources*: Saudi Arabia faces water scarcity challenges domestically, and its agricultural investments abroad often rely on large-scale irrigation. Excessive water extraction from local sources can deplete water resources and have adverse impacts on local ecosystems. Therefore, it is crucial for Saudi investments to prioritize sustainable water management practices, such as efficient irrigation systems and water conservation measures.

*Soil degradation*: Unsustainable farming practices, such as intensive mono-cropping and excessive use of agrochemicals, can lead to soil degradation, erosion, and reduced fertility. It is essential for Saudi investments to promote sustainable agricultural practices, including soil conservation, organic farming methods, and crop rotation, to preserve soil health and prevent long-term environmental damage.

*Deforestation*: Agricultural expansion, as in large investments, can lead to deforestation, particularly in regions with high biodiversity and valuable ecosystems. Saudi investments should prioritize forest protection and avoid investing in projects that contribute to deforestation or habitat destruction. Instead, they should promote sustainable land use practices that maintain forest cover and preserve biodiversity.

### 4.9.2 Social Impact

Host country: If new employment is generated and salaries are fair, it can lead to higher living standards and poverty reduction. This is especially true if agricultural sector dominates or plays an important role in GDP make up. Land, the main economic and social asset for vast rural population must be dealt with carefully, and if land rights are not respected, local communities may be marginalized, potentially resulting in discontent and may even to social unrest.

Investing country: It can assist in meeting local demand for specific agricultural goods, so helping to improve food security. However, if the investments are perceived as exploitative or damaging to the host country, it may result in public disapproval. Common socio-economic concerns of impact of Saudi investment abroad are portrayed below:

*Land rights and local communities*: Large-scale agricultural investments can sometimes result in land acquisitions and displacement of local communities. It is crucial for Saudi investments to respect the land rights of local populations, engage in transparent negotiations, and provide fair compensation for any land taken. Investments should prioritize the well-being and livelihoods of affected communities, ensuring that they benefit from the investment through employment opportunities, skill development, and improved local infrastructure.

*Labor practices*: Saudi agricultural investments abroad should adhere to fair labor standards, ensuring safe working conditions, fair wages, and protection of workers' rights. Labor practices should align with international standards, including the International Labour Organization (ILO) conventions, to avoid exploitation, promote decent work, and uphold human rights.

*Knowledge transfer and capacity building*: Saudi investments should prioritize knowledge transfer and capacity building initiatives to enhance local agricultural practices and empower local farmers. This can involve sharing advanced agricultural technologies, providing training programs, and supporting the development of local agricultural value chains. Such efforts can contribute to sustainable development, improve food security, and foster local economic growth.

*Gender inclusivity*: It is important for Saudi agricultural investments to promote gender inclusivity and empower women in agriculture. This can involve providing equal access to resources, training, and decision-making opportunities, thereby promoting gender equality and contributing to more sustainable and resilient agricultural systems.

To ensure environmental sustainability and positive social impact, Saudi Arabia and its agricultural investment entities should adopt stringent environmental and social safeguards, engage in transparent and inclusive governance practices, and actively collaborate with local stakeholders, governments, and civil society organizations.

Here are some examples:

Positive impacts: Investing in developing countries' agricultural sector is among the most efficient ways to reduce poverty and hunger Foreign direct investment (FDI) in agriculture is expected to contribute to investment in domestic economies, create more jobs, and increase human development index.

Negative impacts: Foreign agricultural investment can lead to reduced access to natural resources and loss of livelihoods, which can generate local opposition to the investment. Negative impacts also include increased food prices and social conflict where local communities are adversely affected. Other negative effects include:

a. Reduced access to natural resources and loss of livelihoods, which can generate local opposition to the investment
b. Disadvantages of large-scale land acquisitions often outweigh the few benefits to the local community
c. Increased food prices and social conflict where local communities are adversely affected
d. Risks for host countries, such as unclear local land rights
e. Decreased capital inflows into agriculture will negatively affect food security and agricultural growth at large.

Overall, foreign agricultural investment can carry risks for host countries, and the negative impacts often outweigh the benefits to the local community unless extra remedial measures have been put in place, often referred to or categorized as "responsible investment", which is a set of principles for responsible investment in agricultural and food systems and is outlined in the "FAO Responsible Investment Charter". On October 15, 2014, the Committee on the Security of Food in the World (CFS) gave its approval to the Principles for Responsible Investment in Agriculture and Food Systems. The overarching goals of these principles are to advance sustainable development, improve food security and nutrition, and assist the gradual fulfillment of the right to adequate food. The principles take into consideration previously established guiding frameworks like the Principles for Responsible Agricultural Investment (PRAI) and the Principles of the United Nations Global Compact. The principles address the many stakeholders that are involved in investing in agricultural and food systems. These stakeholders include governments, investors, civil society groups, and communities: FAO (2013), Anseeu et al. (2012), Cotula and

Polack (2012), Deininger and Byerlee (2011). The following is a list of the FAO Responsible Investment Charter's core principles:

- Having respect for human rights, especially the rights of local communities and indigenous peoples
- ensuring that there is sufficient food and nourishment
- Advancing the cause of gender equality and the advancement of women
- Observing high standards of openness, accountability, and governance
- ensuring a respect for land tenure rights
- Protecting and preserving the natural environment
- Advancing ethical practices in commercial settings
- Guaranteeing a responsible social stance and active participation in the community
- Promoting smallholder inclusion and empowerment
- Encouraging innovation and capacity

The FAO acknowledges that large-scale private investment in agriculture is an element of the development goals of many countries; nonetheless, it is necessary to ensure that such investments are undertaken responsibly, with the goal of maximizing benefits while simultaneously limiting risks. The OECD-FAO Guidance for Responsible Agricultural Supply Chains is a document that offers direction on how to make responsible investments in the agricultural sector. It is a framework that assists agribusinesses and investors in contributing to sustainable development by identifying and managing risks and impacts in their operations and supply chains.

The guidance establishes a global benchmark for responsible business conduct and due diligence along agricultural supply chains.

It applies to entities upstream and downstream in the agricultural supply chain, such as farmers, processors, traders, retailers, and investors.

The guidance addresses a variety of topics, such as labour rights, land rights, environmental sustainability, animal welfare, and food safety. It also details how to implement due diligence processes to identify, prevent, mitigate, and account for adverse impacts in the agricultural supply chain.

The guidelines are intended to be flexible and adaptable to various contexts and supply chains. It includes a self-assessment checklist, a risk awareness tool, and a due diligence guidance document.

### 4.9.3 Sustainability of Agricultural Investment Abroad

Ensuring sustainability of agricultural investment abroad or Foreign Direct Investment (FDI) is crucial to maximize benefits and minimize risks and negative impacts. Here are some ways to ensure sustainability of agricultural investment abroad:

- Respect local communities and their rights, including land tenure rights and human rights.

- Ensure transparency, accountability, and good governance in all stages of the investment process. These are components of popular consent supporting sustainability of FDI.
- Promote environmental sustainability by conserving natural resources, reducing waste, and promoting sustainable production methods.
- Encourage responsible business conduct by investors and companies.
- Promote smallholder inclusion and empowerment to ensure that local communities benefit from the investment.
- Encourage innovation and capacity building to promote sustainable development.
- Ensure social responsibility and community engagement by involving local communities in the investment process. Such social inclusion contributes positively to sustainable engagement of potential actors, thus contributing to sustainability of FDI.
- Foreign direct investment could make a contribution to bridging the investment gap in developing countries' agriculture. This is a potential driving force for promoting FDI and as the time ensuring its sustainability.

However, it is important to ensure that such investments are conducted responsibly, maximizing benefits and minimizing risks. Empowerment of communities and local institutions is of paramount importance in the course of ensuring sustainability. Some important measures to pursue such empowerment of local communities to negotiate with foreign investors in agricultural projects:

- Ensure that local communities have clear and secure land rights.
- Involve local farmers and cooperatives in joint ventures with investment companies.
- Give farmers a share of the capital invested by foreign investors.
- Ensure that marginalized groups, such as women, are included in the investment process.
- Strengthen the governance and capacity of institutions in host developing countries to negotiate on behalf of local communities.
- Encourage foreign investors to contribute to local values and development.

According to United Nations food agency (United Nations News 2012) and (Reliefweb 2012), investment projects that combine investors' capital, technology and management with the knowledge, land and labour of local farmers are the most successful, while those that simply acquire land are less likely to have any benefits for the host country, foreign investments must give local farmers an active role and leave them in control of their land if they are to have a positive effect on the host country's economy and advance development.

The report recommends that foreign investments give farmers a share of capital, establish joint ventures between investment companies and farmer cooperatives, and ensure that marginalized groups such as women are included in the investment process. Another way to empower local communities is to ensure that they have clear and secure land rights. Additionally, strengthening the governance and capacity of institutions in host developing countries can help them negotiate on behalf of local communities.

### 4.9.4 Challenges, Lesson Learned and Risks of Saudi Investment Abroad

Investment in agricultural projects abroad faces, apart of opportunities, some challenges and risks of various nature. There are lessons to be learned from investment abroad in general and that of Saudi Arabia in particular. Key challenges and lessons include:

Cultural and Environmental Differences:

Investing in agricultural projects abroad means dealing with different cultural norms, practices, and environmental conditions. These differences can impact the success of the investment, as local customs and traditions may affect the management and operations of the project. Understanding and adapting to these differences is crucial to ensure smooth operations.

Political and Legal Frameworks:

Political stability and a favorable legal framework are important for the success of agricultural investments abroad. Changes in government policies or regulations can significantly impact the investment, leading to uncertainties and potential risks. Saudi investors need to thoroughly analyze the political and legal environment of the target country and establish strong relationships with local authorities to mitigate such risks.

Infrastructure and Logistics:

Agricultural investments often require robust infrastructure, including transportation networks, irrigation systems, and storage facilities. In some countries, the lack of adequate infrastructure can pose significant challenges to the productivity and profitability of the investment. It is important for Saudi investors to carefully assess the infrastructure capabilities of the target country and develop strategies to overcome any limitations.

Water Scarcity and Sustainable Practices:

Water scarcity is a global challenge, and it is particularly relevant to agricultural investments. Saudi Arabia itself faces water scarcity issues, and investing in water-intensive crops or regions with limited water resources abroad can exacerbate this challenge. Lessons learned from these investments include the need to prioritize sustainable water management practices, such as water-efficient irrigation systems and crop diversification.

Risk Management and Market Volatility:

Agricultural investments are exposed to various risks, including fluctuations in commodity prices, weather events, and pests/diseases. These risks can significantly impact the profitability of the investment. Saudi investors should develop comprehensive risk management strategies, including diversification of crops and markets, insurance coverage, and contingency plans to mitigate potential losses.

Local Community Engagement and Social Responsibility:

Building strong relationships with local communities is essential for the success of agricultural investments abroad. Understanding and respecting the social and cultural dynamics of the host country is crucial in order to gain acceptance and cooperation from local communities. Lessons learned emphasize the importance of engaging with stakeholders, addressing their concerns, and implementing sustainable practices that benefit both the investment and the local population.

Technology Transfer and Capacity Building:

Investing in agricultural projects abroad provides an opportunity for technology transfer and capacity building. Sharing Saudi Arabia's expertise in advanced farming techniques, irrigation systems, and agricultural research can enhance productivity and local knowledge. Building partnerships with local farmers, universities, and research institutions can foster knowledge exchange and long-term sustainability (Thomas et al. 2019).

In summary, investing in agricultural projects abroad presents various challenges and opportunities for Saudi Arabia. By understanding and addressing these challenges and incorporating lessons learned, Saudi investors can enhance the success and sustainability of their agricultural investments while contributing to food security and economic growth both domestically and globally.

Due to difficulties that are connected with investing in greenfield agricultural projects in developing nations, a great number of projects have either been scrapped entirely or are in the process of being brought online. In times of high food prices and water shortages, the chance that the host government would back out of its pledges is one of the risks. Another risk is the potential for social strife in areas where local residents will be negatively affected.

There is a growing awareness among Investors about opportunities of investment in countries where food insecurity dominates and also they have become increasingly aware with environmental, social, and governance issues that are associated with these projects. For instance, SALIC invests in nations that have the agricultural potential to produce staple agricultural commodities for exports such as wheat, barley, corn, rice, and sugar, in order to ensure a steady supply of these commodities.

In addition, there is competition for farmland from neighboring countries that are rapidly industrializing. China, South Korea, and India each have their own issues with food security, and all three countries have emerged as aggressive purchasers of farmland in other parts of the world.

## 5 Conclusions

### *5.1 Summary of Saudi Investment Abroad*

The agricultural investments made by Saudi Arabia overseas are crucial in many important respects:

Saudi Arabia has recognized the significance of ensuring food security for its people despite the country's limited domestic agricultural resources and rising population. The government is trying to ensure that its citizens always have access to food by funding agricultural initiatives in other countries. By bolstering domestic production, these investments improve food security and lessen reliance on foreign suppliers.

Saudi Arabia, which has relied heavily on oil profits in the past, is now aggressively working to diversify its economy away from oil. Increasing the agricultural sector and opening up new avenues for non-oil income generation are two ways in which agricultural investments overseas help to this diversification plan. Investments like this help the economy expand, new employment being created, and the agricultural value chain as a whole advances.

Saudi Arabia is able to foster international relationships and develop diplomatic ties with host nations via agricultural investments overseas. The Kingdom may build lasting connections via agricultural partnerships predicated on the three pillars of shared interests, shared learning, and technology transfer. The benefits of these collaborations are not limited to the agricultural sector; they may also have a favorable effect on other areas, such as commerce, investment, and even cultural exchange.

Investments overseas allow Saudi Arabia to share its cutting-edge agricultural methods and technology with host nations. This sharing of information helps strengthen agricultural capacities in the area, raises output, and encourages more environmentally friendly methods. Saudi Arabia helps ensure the long-term food security and economic stability of host nations by investing in the growth of local agricultural industries.

By funding agricultural initiatives overseas, Saudi Arabia hopes to lessen its exposure to the ups and downs of global food prices and market fluctuations. A country's capacity to regulate its food supply and weather external market swings and geopolitical concerns improves when it has a diverse portfolio of agricultural assets.

Food security, economic diversification, and the development of international connections are all bolstered by Saudi Arabia's agricultural investments overseas. The nation's strategic aims of securing a reliable food supply, decreasing its dependency on oil revenues, and fortifying its diplomatic relations are all advanced by these expenditures.

### *5.2 Prospects for Future Collaboration in Investment Abroad*

Continued collaboration in investment abroad in the agricultural sector has the potential to address global challenges and achieve mutual benefits. Investing in developing countries' agricultural sector is among the most efficient ways to reduce poverty and hunger. Therefore, continued investment in the agricultural sector can help to address global challenges such as food insecurity and poverty. International collaboration is extremely important for the future of agriculture within countries and around the world. Collaborating with other countries can help to share knowledge, resources, and technology, leading to more efficient and sustainable agricultural practices.

Private investments in agricultural research and development (R&D) account for only 10–15% of total investments. Therefore, continued collaboration in investment abroad can help to increase private sector investments in the agricultural sector, leading to more innovation and growth.

The growth in food demand will require at least $80 billion annual investments, and most of this will need to be sourced from the private sector. Therefore, continued collaboration in investment abroad can help to attract foreign direct investments into the sector, leading to more growth and development.

Saudi Arabia's King Abdullah Initiative for Saudi Agricultural Investment Abroad has targeted 35 countries for agro-investment, with the aim of producing basic and strategic commodities for food security for both the Kingdom and target countries. Continued collaboration in investment abroad helps to achieve these goals and contributes to realizing national and international food security.

Overall, continued collaboration in investment abroad in the agricultural sector has the potential to address global challenges such as food insecurity and poverty, increase private sector investments in the agricultural sector, and attract foreign direct investments into the sector. Collaborating with other countries can help to share knowledge, resources, and technology, leading to more efficient and sustainable agricultural practices.

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# Chapter 7
# Food Supply Chain in Saudi Arabia

**Abda Abdalla Emam and Nagat Elmultham**

**Abstract** The food supply chain plays a vital role in achieving food security. This chapter aims to highlight the food supply chain in Saudi Arabia. Saudi Arabia is located in the Arabian Peninsula and is surrounded by different countries. In terms of consumption, KSA is considerably increasing its use of food products due to various reasons, including unsuitable farming conditions for agricultural food products. Therefore, Saudi Arabia relies on both local production and imports. Saudi Arabia imports the majority of its rice from India and wheat from other countries. KSA is rich in the production of dates. The food supply chains of wheat, rice, vegetables, and dates were examined in this chapter. Additionally, the chapter discusses the link between the supply chain and food security, concluding that an effective food supply chain leads to achieving food security. Furthermore, the chapter reveals the strategies used by KSA to overcome the COVID-19 crisis and attain a sustainable food security chain.

**Keywords** Date · Food security · Rice · Saudi Arabia · Supply chain · Wheat

A. A. Emam (✉) · N. Elmultham
Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al Ahsa 31982, Saudi Arabia
e-mail: aaeali@kfu.edu.sa

N. Elmultham
e-mail: nelmultham@kfu.edu.sa

A. A. Emam
Department of Agricultural Economics, Faculty of Agricultural Studies, Sudan University of Science and Technology, Khartoum, Sudan

N. Elmultham
Department of Agricultural Economics, Faculty of Agricultural Sciences, University of Gezira, Wad Madani, Sudan

 
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# 1 Introduction

Saudi Arabia is located on the Arabian Peninsula and has a large share of the land. It is bordered by Bahrain, the United Arab Emirates, Jordan, Iraq, Oman, Qatar, Kuwait, and Yemen (Fig. 1). The country has a climate that features mostly desert and semi-arid regions. Historically, the central and southwestern regions of Saudi Arabia were economically prosperous and populated. However, the discovery of massive petroleum reserves shifted the focus of the economy and population distribution to these regions. A map showing Saudi Arabia's population distribution can be found in Fig. 1. The country has an extensive logistics communications system that includes numerous land, air, and seaports (Figs. 2 and 3). Consequently, Saudi Arabia is well-integrated with the international market and able to supply a wide range of commodities.

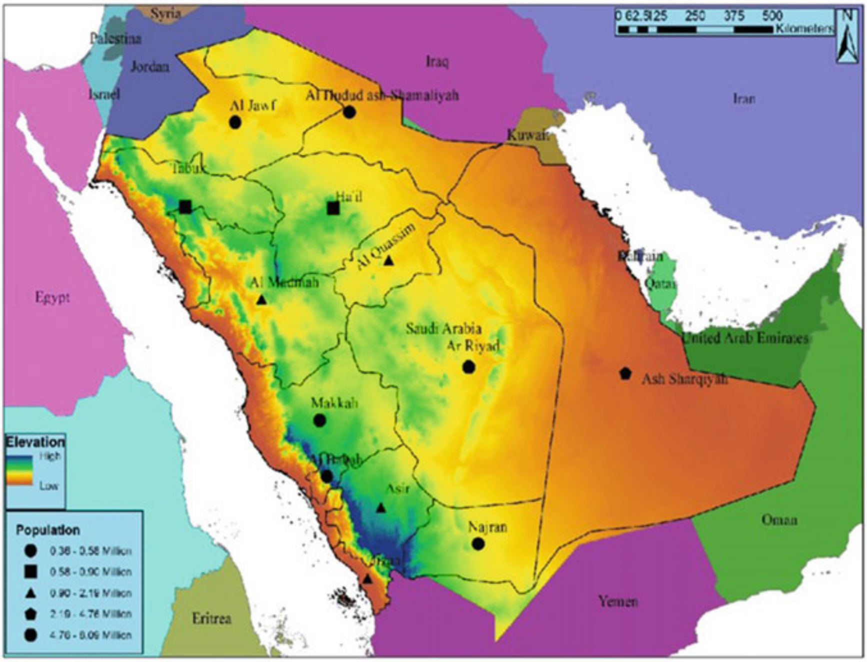


**Fig. 1** Saudi Arabia population density. *Source* https://www.researchgate.net/profile/HasanKhalil/publication/303383204/figure/fig1/AS:491795982360576@1494264707484/Saudi-Arabia-its-varied-terrain-and-population.png


**Fig. 2** Saudi Arabia roads map. *Source* https://previews.123rf.com/images/pbardocz/pbardocz1905/pbardocz190500627/122618192-high-detailed-saudi-arabia-road-map-with-labeling-.jpg

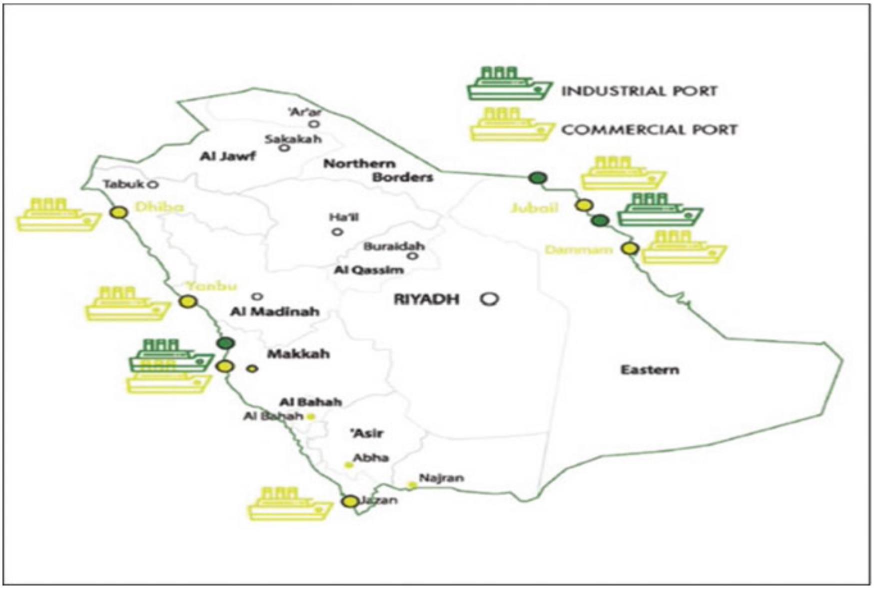


**Fig. 3** Saudi Arabia ports maps. *Source* https://www.ic.gov.sa/media/1385/t1.png

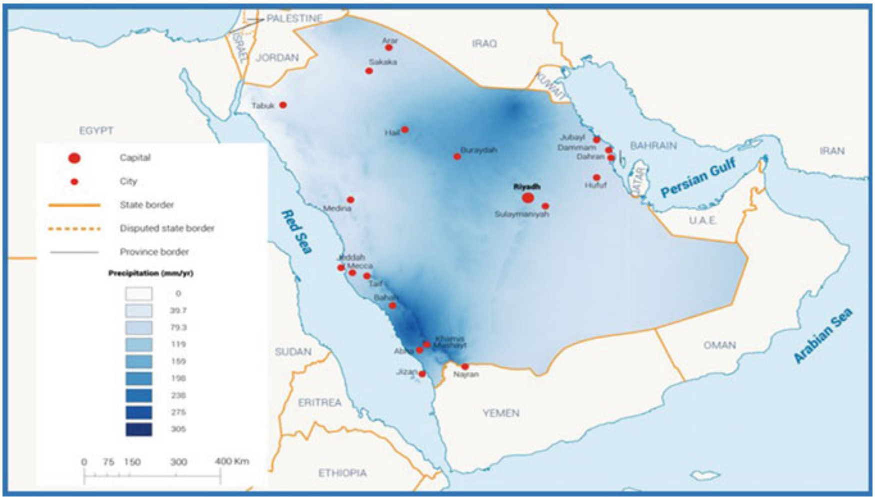


**Fig. 4** The rain quantities in KSA. *Source* https://water.fanack.com/wp-content/uploads/2021/06/11_SAUDI_rainfall_3000px.png

## 2 Food Supply in Saudi Arabia

In terms of food supply sources, Saudi Arabia depends on both local and imported sources. However, local production of food faces numerous obstacles, including the unsuitable farming circumstances for growing agricultural food products, low availability of irrigation water, and low levels of rainfall (Fig. 4). Only 1.5% of Saudi Arabia's total area is considered arable land. As a result, the country is unable to harvest enough agricultural food crops to meet its internal demand, leading to a noticeable resource insufficiency and an increasing need for government involvement in the agricultural sector. In recent years, the Saudi government has also taken steps to direct farming away from water-intensive crops through changes in its acquisition and subsidization programs, further limiting the country's internal agricultural production.

## 3 Food Consumption in the Saudi Arabia

Regarding food consumption, Saudi Arabia has seen a substantial increase in food and beverage products (Figs. 5, 6, and 7). This rise in consumption can be attributed to the increasing population, with a total population of 30,917 and 34,269 people in 2014 and 2019, respectively, with an annual growth rate of 11% (FAO 2023).

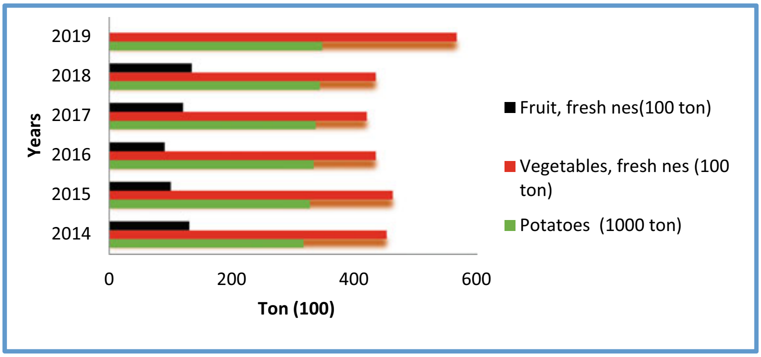


**Fig. 5** Food consumption in KSA: fruits, vegetables and potatoes. *Source* Based on data from FAO

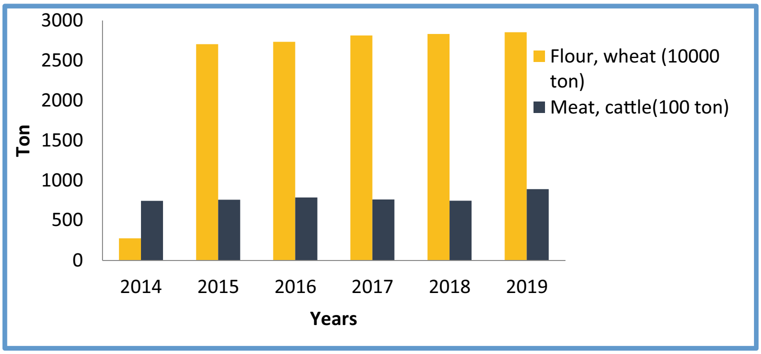


**Fig. 6** Food consumption in KSA: Meat cattle and flour wheat. *Source* Based on data from FAO

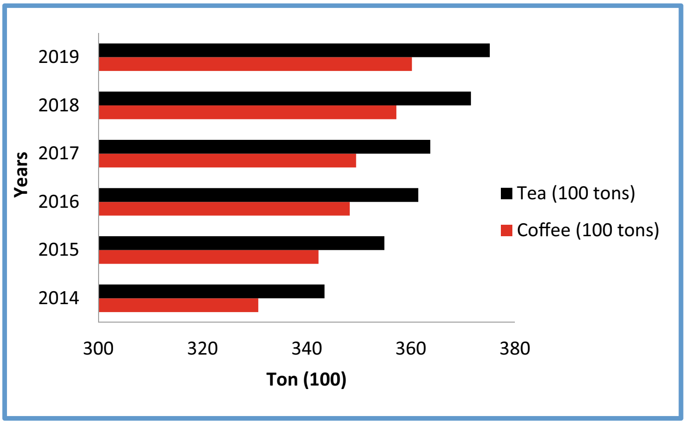


**Fig. 7** Food consumption in KSA: Coffee and Tea. *Source* Based on data from FAO

## 4 Food Supply Chain

The food supply is a complex system consisting of a series of processes that transform agricultural crops into a form suitable for consumption by the end user (Haji et al. 2020). Food supply chains are dynamic and comprised of various steps that affect the cost, quality, and distribution time of a product, starting from the agricultural phase up until the final consumer (Haji et al. 2020; Paam et al. 2016). Effective management of the food supply chain depends on many factors, including an organized supply chain that can ensure proper delivery and prompt customer service while reducing the overall expenses involved in the process (Pang et al. 2015). It is also crucial to understand what makes a moral food supply chain, which primarily involves offering the necessary amount of nutrition within safety guidelines while also providing affordable and accessible food (Krystallis et al. 2007; Mohammad et al. 2009). The supply chain encompasses the entire process of obtaining raw materials, distribution, transformation, processing, transfer to traders, and finally to the end customer (Ganeshan 1995). In terms of food safety, the supply chain refers to the distribution of food quality, a concept that has gained traction in recent years (Krystallis et al. 2007; Mohammad et al. 2009). Others consider the supply chain as the coordination of all activities that match consumer demand (Chopra and Meindl 2010). According to Guohua (2013), the typical supply chain consists of suppliers/producers, manufacturers/processors, storage facilities/warehousing units, distributors/shipping companies, retailers/wholesale accounts, and end consumers, all of which are connected by communication and transportation. From the author's point of view, the supply chain involves all production and marketing processes, including marketing channels. From a systems perspective, Supply Chain Management (SCM) includes all activities related to the transformation of raw materials into finished products (Christopher 1992; Shah and Singh 1999). SCM also encompasses logistics activities within and between companies, coupled with resource and information planning and control (Chen and Paulraj 2004).

## 5 Food Supply Chain in Saudi Arabia

In reference to food sources, Saudi Arabia relies on both local production and imports. It imports the majority of rice from India and wheat from other countries. However, it is rich in the production of dates. The food supply chain in Saudi Arabia begins with production and follows the marketing channel illustrated below.

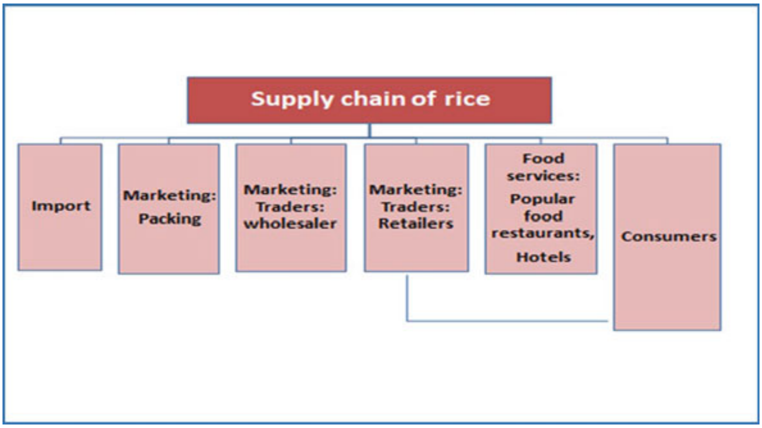


**Fig. 8** Supply chain of rice in Saudi Arabia. *Source* Drawn by authors, Saudi Grains Organization, annual report 2018

## *5.1 Food Supply Chain for Imported Food in Saudi Arabia*

### 5.1.1 Supply Chain of the Imported Rice

The supply chain for imported rice is depicted in Fig. 8. The diagram illustrates two channels through which the rice flows. In the first channel, the rice goes from import to packing, then to wholesalers and retailers, and eventually reaches consumers. The second channel follows a similar path but also includes food services as an additional step between retailers and consumers.

### 5.1.2 Supply Chain of Imported Wheat

As depicted in Fig. 9, the supply chain for imported wheat involves several stages: importation, milling, packing, distribution to wholesalers, sale to retailers, and ultimately delivery to consumers either directly or indirectly through food service providers.

## *5.2 Food Supply Chain in Saudi Arabia (Local Production)*

### 5.2.1 Supply Chain of Local Food: Dates

Figure 10 illustrates the supply chain for dates. Dates may be purchased as fresh fruit or after processing. For fresh dates, the supply chain begins with the farmers and ends with the consumers, either directly or indirectly through retailers. The supply chain

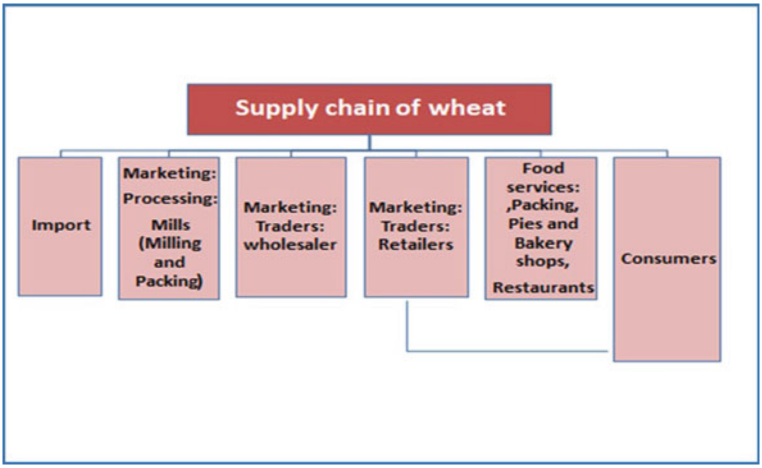


**Fig. 9** Supply chain of wheat in Saudi Arabia. *Source* Saudi Grains Organization, annual report 2018

for processed fruit begins with the farmers and involves wholesalers, processors, retailers, and consumers. In the case of exporting, the supply chain involves the processor.

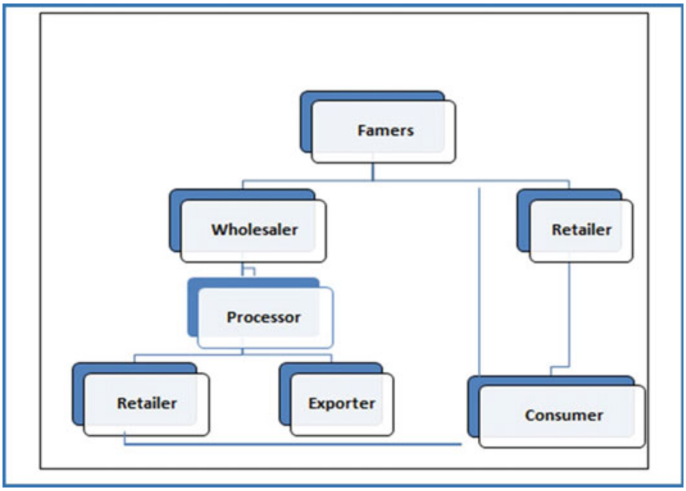


**Fig. 10** Supply chain of Dates in Saudi Arabia. *Source* Drawn by authors

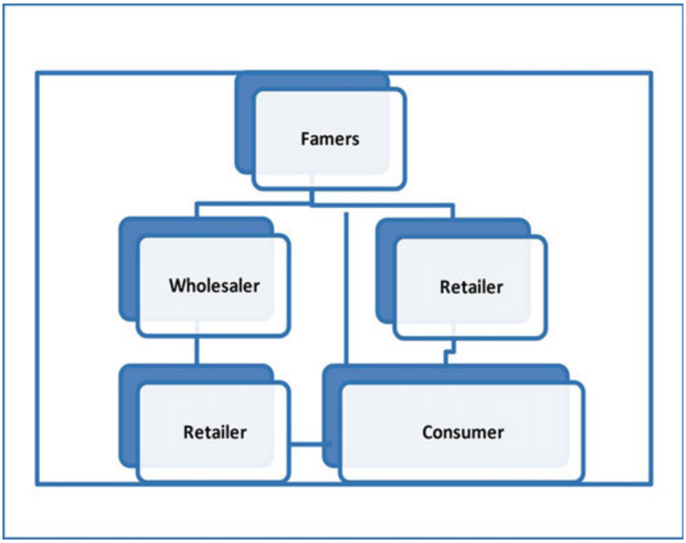


**Fig. 11** Supply chain of vegetable- fresh in Saudi Arabia. *Source* Drawn by authors

### 5.2.2 Supply Chain of Local Produced Food: Vegetables

The supply chain for vegetables is illustrated in Fig. 11. The fresh vegetable chain starts from the farmers and goes to the retailers and consumers. Alternatively, it can begin from the farmers to the wholesalers, retailers, and then consumers.

## 6 Food Supply Chain and Its Impact on Food Security

Food security can be defined as having sufficient access to food for consumption and utilization (Aneesh 2017; FAO 2008; Ramasamy and Hiepe 2009). According to Swaminathan and Bhavani (2013), food production is essential for the availability of food. The supply chain is made up of many nodes, each playing a role in the movement of goods from one point to another (Al Fayad 2016). Guohua (2013) defines a supply chain as including suppliers or producers, manufacturers or processors, storage facilities and warehouses, distributors and shipping companies, wholesale and retail, and ultimately consumers. Supply chains can contribute to food availability and accessibilty (the first and second pillars of food security) (Sjah and Zainuri 2020). Supply chains are essential in increasing food availability by improving technologies of seed culture, irrigation, crop maintenance, harvesting, and post-harvest handling to reduce food loss. They can help directly by increasing people's income (through job creation) and indirectly by providing access to food markets. By generating jobs for participants and workers in their supply chains, there is increased income for people to purchase food. Food waste occurs in the supply chain from the start of agricultural production to the final consumption (Gustavsson et al. 2011), and using efficient and effective supply chains will lower waste and increase food supply, which is a component of food security. Therefore, supply chains can contribute significantly to achieving food security.

During the COVID-19 pandemic, Saudi Arabia's economy proved to be robust enough to allow for the importing of essential food through a market-based food security approach (Alsuwailem et al. 2022). In reference to a sustainable development program, Saudi Arabia is preparing and producing an exceptional supply chain that is both sustainable and accountable. This is being accomplished by implementing innovative planning systems to enhance the movement of goods, full account perceptibility through the growth of infrastructure, logistics modeling, and technology to improve transportation efficiency. Logistics modeling is also being employed to provide tools for boosting warehouses and creating better distribution (Alsuwailem et al. 2022; Saudi Arabia National Portal 2023). At a national level, food security is defined as "all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO 1996). Food insecurity can arise due to a market-based food supply, which is impacted by events such as natural disasters and a reduction in the flow of food transfers. This puts importing countries at the highest risk of food insecurity (Alsuwailem et al. 2022; Lovelle 2015). The coronavirus pandemic (COVID-19) is considered a food security risk as it severely disrupts economies (Alsuwailem et al. 2022; Althumiri et al. 2021; Moretto and Caniato 2021). It affects the global food supply chain, transportation capacity, and food production (Alsuwailem et al. 2022; Althumiri et al. 2021; Barman et al. 2021). To mitigate this risk, Saudi Arabia has implemented several strategies, including focusing on the sustainability development goals outlined in Vision 2030, specifically the goal of food security. Saudi Arabia is aiming to achieve sustainability in its food supply chain by directing foreign investment in agriculture through partnerships with other countries and increasing and optimizing cultivated land by SR 1.9 billion (USD 506.67 million) in 2019 (Alsuwailem et al. 2022).

## 7 Conclusions and Prospects

The food supply chain plays a vital role in realizing food security. Saudi Arabia relies on both local production and imports, with the majority of rice and wheat being imported from India and other countries. Saudi Arabia is rich in the production of dates. The food supply chains for wheat, rice, vegetables, and dates have been analyzed. There is a clear link between the supply chain and food security, with effective food supply chains leading to the achievement of food security. Additionally, the chapter discusses the strategies implemented by Saudi Arabia to overcome the COVID-19 crisis and attain food security. This success is due to the fact that Saudi Arabia has previously practiced numerous strategies and has operated on the sustainability development goals of Vision 2030, particularly the goal of food security.

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# Chapter 8
# Agricultural Finance Towards Food Security in Saudi Arabia

**Mutasim Mekki Elrasheed, Somaia Rogaime Jaffar, and Adam E. Ahmed**

**Abstract** Achieving food security is the main target that all countries strive to realize. The provision of finance for agricultural projects and activities is the key factor for sustaining food security. For Saudi Arabia, the Kingdom has prioritized food security in its Vision 2030. This chapter aimed to shed light on the role played by agricultural finance in achieving food security in the Kingdom of Saudi Arabia (KSA). It also sheds light on the Agricultural Development Fund (ADF): general requirements for accepting applications for credit services, lending terms, credit services, and others. It is evidence that KSA has realized the importance of agricultural finance in sustaining food security thus establishing the ADF. It has also assigned the role of sustaining KSA food security to the Ministry of Environment, Water and Agriculture (MEWA) represented by the General Food Security Authority (GFSA). The ADF is playing a crucial role in sustaining food security in KSA through liaising with MEWA and the National Development Fund in the provision of support, credit, and consultancy to agricultural investors (investing locally and/or abroad) and importers. The annual values of ADF's loans distributed to beneficiaries are increasing over time by 13.7 million US Dollars/annum. It is clear that the ADF has contributed effectively to enable the Kingdom to achieve its current situation of food security, which can be called stable and food secure.

M. M. Elrasheed (✉) · A. E. Ahmed
Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: melrasheed@kfu.edu.sa; mutasimmekki@yahoo.com

A. E. Ahmed
e-mail: ayassin@kfu.edu.sa; adamelhag2002@yahoo.com

A. E. Ahmed
Department of Agricultural Economics, Faculty of Agriculture, University of Khartoum, Khartoum, Sudan

S. R. Jaffar
Department of Agricultural Economics and Agribusiness, College of Agriculture, University of Bahri, Khartoum, Sudan
e-mail: gafarsomaia1973@gmail.com

 
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## 1 Introduction

The world is witnessing major challenges in how to meet the growing food demand for the rapidly increasing world population, which according to the UN (2017) is forecasted to reach 11.2 billion people by 2100. Thus, to meet the global demand for food, agricultural production must be substantially increased. This could be done by improving land and labor productivity, along with access to finance and agricultural inputs. There is also an urgent need to develop appropriate measures and supportive policies that might lead to a significant increase in agricultural investment. Moreover, investing in smart agricultural technologies and practices to enable farmers in improving their production is also critical in addressing malnutrition and poor farmers' incomes. Thus, the provision of support and appropriate finance is fundamental in applying innovations and encouraging investment, which in turn improves food production and sustains food security.

Saudi Arabia has given special attention to food security in Vision 2030. It also assigned the role of the supervision and follow-up of achieving food security in the Kingdom to the Ministry of Environment, Water and Agriculture, represented by the General Food Security Authority (GFSA). In the same vein, it established the Agricultural Development Fund (ADF) for the purpose of the provision of funds, support, and consultancy in the field of agricultural investment. The ADF liaises with MEWA and related institutions in achieving food security in the Kingdom. In this regard, it is worth noting that, the contribution of the agricultural sector to the Kingdom's GDP during the past 57 years was 392.8 billion US Dollars, whereas, the contribution of ADF to the GDP and the agricultural GDP of the kingdom was 35.47 billion US Dollars, and 9%, respectively (ADF 2020b).

Based on the substantial role played by agricultural finance in improving farmers' income and agricultural productivity, the objective of this chapter is to highlight the important role played by agricultural finance on food security in the Kingdom of Saudi Arabia (KSA). It provides an overview of the basic concepts of both agricultural finance and food security, the role of agricultural finance in sustaining food security in KSA, the Agricultural Development Funds, and food security, and finally draws conclusions and outlines prospects.

## 2 Concept of Food Security

Food security is defined according to the World Food Summit in 1996 as a situation that "exists when 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" (FAO 1996). The state of food security is determined through the interaction of different factors ranging from political, social, economic, and agricultural to health factors. In fact, food security has four distinct, but interrelated dimensions that must be fulfilled simultaneously: physical availability of food, economic and physical access to food, food utilization, and stability (Ahmed et al. 2023). Physical Availability of Food addresses the "supply side" of food security and is determined by the level of food production, levels of stock, and net trade (Brown et al. 2015). Economic and Physical Access to Food refers to an adequate supply of food at the national or international level but does not guarantee household-level food security. Concerns about lack of access to food have led to increased policy attention on income, spending, markets, and prices in attaining food security goals.

Food Utilization refers to how the body uses the food. Adequate food intake is the result of good care and feeding practices, food preparation, diet diversity, and food distribution within the household along with good biological use of the food consumed, and this governs the nutritional status of individuals. Whereas, food Stability refers to the sustainability of all food security dimensions over time. Even if individuals eat enough food today, they are still considered food insecure because they might not have sufficient access to food periodically. It is worth noting that bad climate situations, political instability, or economic factors have a significant impact on food security conditions.

On the other hand, food insecurity is defined as "a situation that exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life" (FAO 1996). Food insecurity can be divided into two types depending on the period of insecurity: Chronic food insecurity and transitory food insecurity (FAO 2008). Chronic food insecurity is a long-run or persistent phenomenon that occurs when individuals are incapable of satisfying their least possible food needs for a prolonged time, due to prolonged exposure to poverty, lack of assets, and insufficient access to productive or financial resources. It can be addressed with long-term development measures, such as education or facilitating access to production inputs through facilitating credit. Whereas, Transitory Food Insecurity: refers to temporary, short-term events resulting from a sudden decrease in the individual's ability to produce or obtain adequate food to maintain their nutritional status, due to short-term shocks and fluctuations in food availability and access, including year-to-year changes in food production and prices, and family income (FAO 2008). Addressing the problem of transitory food insecurity requires intervention through an early warning system and safety net program. There is also seasonal food security. Seasonal food security: is the situation that happens when an individual falls between the two types of food insecurity: chronic and transitory. It is usually expectable and follows a series of recognized events (limited duration). It happens due to the presence of a cyclical pattern of insufficient food availability and accessibility coupled with seasonal variations in weather conditions, cropping patterns, job opportunities, and disease. On the other hand, the term vulnerability refers to the likelihood of a sharp decline in food access, or consumption, concerning a specified value that determines the least possible levels of food required by human well-being (FAO 2008). Accordingly, vulnerability is the summation of two things: exposure to risk and risk management. Risk exposure is the "probability of an event or shock", if it happened, would inversely affect the household such as drought, floods, and others. On the other hand, risk management refers to the capability of a household to mitigate the consequence of possible shocks. It can be accomplished through the adoption of different coping strategies.

The world has made great efforts to eradicate poverty and address global food insecurity, however, the number of undernourished people around the world started to increase slowly in 2015 after long periods of decline. Statistics showed that in 2020, there are 3.1 billion people in the world who may not have access to safe and healthy food. Moreover, the number of people affected by hunger in the world is expected to exceed 670 million by 2030 (FAO et al. 2022).

## 3 Concept of Agricultural Finance

It is essential to shed light on some financial terms before proceeding forwards. Borrowing: is defined as the use of something belonging to others with the intent of returning it back, with or without cost, and in an agreed-upon manner. It is also considered the transfer of control over resources from the lender to the borrower according to certain conditions. Whereas a loan is defined as the sum of money that the borrowers should pay back with interest. It also refers to the act of lending something to someone. In the case of money: the lender is the owner of the money whereas the borrower is the investor given that the borrower undertakes to return the money in the future.

Credit and Debt: the two words have to do with owing money, yet are not the same. Debt is money that investors owe, whereas credit is the money the investor can borrow. That is, credit is synonymous with borrowing or crediting. Thus, investors can form debt through credit (borrowing money). However, agricultural finance is defined as the provision of the necessary money for investment in the agricultural sector (e.g. agricultural production and reproduction including activities such as storage, transport, sales, and marketing), regardless of its source (self or borrowing), so agricultural finance is more comprehensive than borrowing.

Agricultural loans are used as a means to advance agricultural development, improve net income and raise the farmers' standard of living by providing or achieving the following:

(a) Increase capital formation in the agricultural sector.
(b) Maintain an appropriate size of agricultural activity (to take advantage of economies of scale).
(c) Increase production efficiency (such as the owner obtaining modern machines - purchasing fertilizers and improved seeds).
(d) Increase the ability to cope with the changing economic conditions (such as replacing means of production to keep pace with technical developments).

(e) Confront seasonal fluctuations in income and expenditure.
(f) Protect from unforeseen (favorable) natural conditions.
(g) Enable ownership.

## 4 Agricultural Finance and Food Security

Agricultural finance is considered among the main factors that affect agricultural development and food security in any country. It plays a critical role in both the supply (food availability) and demand side (food accessibility) of food security. It affects the food availability (production) pillar of food security through the provision of the right quantity and quality of input, enhancement of agricultural operation and harvest, in addition to facilitating the marketing of agricultural output. Whereas, it directly affects food accessibility through the provision of funds and indirectly through the income generated from the invested loans. Moreover, Asghar and Salman (2018) mentioned that removing the constraints facing the provision of agricultural finance improves agricultural production, and in turn, decreases food insecurity levels by ensuring the availability of food for all. However, it is worth noting that most of the farmers living in the rural areas of the developing countries are poor, and in desperate need of credit to carry out their agricultural activities. Moreover, they are not able to purchase the right inputs in terms of quantity and quality, consequently, their productivity remains low (Sheik and Abbas 2007). According to Islam (2020), the provision of formal agricultural credit helps small-scale poor farmers to obtain agricultural inputs at the right time and place, thus increasing food production and improving the livelihoods of poor farmers. He also argued the presence of both short and long-run relationships between agricultural credit and agricultural productivity and stresses the importance of increasing the provision of agricultural credit on improving agricultural production, which in turn nurtures economic growth in Bangladesh.

The type and severity of risks that farmers face vary across their agricultural systems, their physical and economic conditions, and the prevailing state policy (Klein et al. 1999).

The techniques of microfinance applied in urban areas of developing countries can provide good models for agricultural lending operations in rural areas. Problems involving high risks and costs limit agricultural production and financing (Klein et al. 1999). Furthermore, Onyiriuba et al. (2020) Stresses on the importance of using financing policies to improve agricultural production and ensure food security. These policies should also be accompanied by complementary measures to address risk aversion tendencies among lenders, weak credit guarantees, subsidies, and budget allocations to agriculture. Additionally, the importance of ensuring the effective commitment of lenders to direct financing towards agriculture and agricultural insurance support is also essential. Of course, the success of these policies requires strong links to the agricultural credit access and monitoring chain.

These policies should also be directed toward rural development targets target youth, women, and smallholder farmers.

Generally, financial institutions are usually confronted with different types of risks, the most important of which are: credit or loan default risk, liquidity risk, interest rate risk, and foreign exchange risk (Klein et al. 1999). These risks have a significant impact on farmers' borrowing and the financial institutions that provide them with loans. However, good management can play a major role in reducing these risks. It is worth noting that risks and uncertainties affect agricultural production more than most other activities. The unpredictability of how much losses are associated with production could have a significant negative impact on farmers' incomes and their ability to repay their loans. On the other hand, (Lin et al 2022) confirmed the presence of a statistically significant positive effect of inclusive digital financing on food security in the marketing areas of the main grain of China, in addition to the balanced production and marketing areas. They also found a non-statistically significant effect of inclusive digital financing on food security in the main grain production areas.

## 5 Agricultural Development Fund and Food Security in KSA

Several years ago, the ADF launched seven initiatives to address the challenges facing the agricultural sector and to ensure sustainable food security in the Kingdom, namely (ADF 2019):

(a) Agricultural Information Center (Manar) initiative,
(b) Rationalization of water use in agricultural crops (except for wheat and green fodder),
(c) Develop handling and marketing of agricultural crops methods (vegetables and fruits). In addition to initiatives of:
(d) Raise the efficiency of the poultry sector,
(e) Development of palm and dates sector,
(f) Improvement of sheep breeding and initiative, and
(g) Development of the fisheries sector.

However, in 2020 the ADF initiated three initiatives, worth 988.8 million US Dollars to overcome the negative effects of COVID-19. The first initiative deals with the postponement of due loan installments: the total amount of funds allocated for the initiative are 40 million US Dollars, and the total beneficiaries were 4398. The second initiative is the encouragement of small and medium-scale enterprises (direct and indirect loans): here 243.47 million US Dollars were allocated for this initiative. The third one is the initiative of financing the import of targeted agricultural products in the food security strategy: here 480 million US Dollars were assigned as bank guarantees for importing crops like rice, soybeans, corn, red meat, soybeans, and sugar. (ADF 2020a). Before the virus outbreak, the ADF's budget had already risen about 60% from a year earlier, including allocating 0.27 billion US Dollars for overseas investment. It is worth noting that food security is one of the main goals of KSA Vision 2030 that ADF liaises with MEWA, the National Development Fund, and other related institutions to achieve. The overseas funding offers low-interest loans for companies, which cultivate crops like alfalfa, wheat, barley, sugar, rice, and corn and send at least half of their output to Saudi Arabia. Increasing home production of fruit and vegetables is one of the Kingdom's top priorities. Accordingly, the ADF offers loans that cover a larger share of capital investments for hydroponics and technology that uses 90% less water than traditional farming methods (ADF 2021).

The actual ADF distributed loans have increased steadily over time, it increased from 244.37 million US Dollars in 2011 to 361.52 million US Dollars in 2015, and however, it dropped to 164.67 million US Dollars in 2017 and then increased again to reach 474.56 million US Dollars in 2020. It is also clear from the trend line of the distributed loans for the period 2011–2020 ($Y = 13.675X + 211.58$, where y = actual distributed amount of loans and X = years), that the amount of distributed loans increased steadily over time with 13.675 million US Dollars/year (Fig. 1). However, the number of borrowers showed a fluctuating trend over time. It increased from 3,923 as an average for the period 2011–2015 to 4524 in 2017 then decreased to 2905 in 2019 and increased to 3,999 borrowers in 2020 (Table 1).

It is worth noting that, the total number of approved loans since the start of the ADF's activity until the end of the fiscal year 2021 was 467,949 and the total approved value was 14.67 billion US Dollars (ADF 2021). Out of which, 4.53 billion US Dollars was distributed to 5395 specialized agricultural projects. The poultry sector (broilers, laying eggs, hatchers, grandmothers, automated slaughterhouses) occupied the first position with 1370 numbers of loans representing 26% of the total number of specialized agricultural projects and more than 1.6 billion US Dollars representing (32%) of the total value of loans provided for them (ADF 2021). Moreover, greenhouse

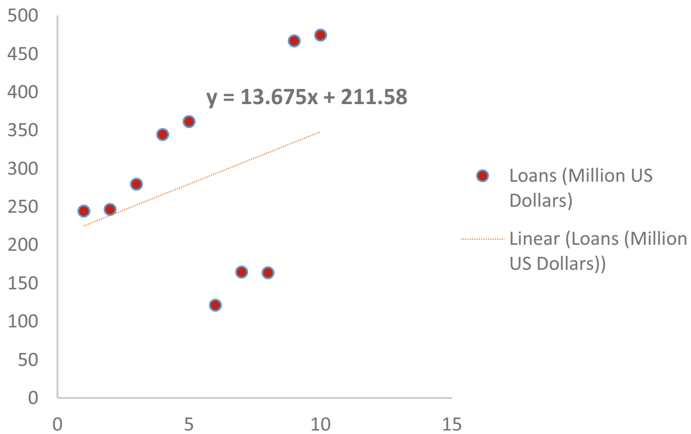


**Fig. 1** Saudi Agricultural Development Fund: Amount of lending loans (Million US Dollars) and numbers of beneficiaries for the period 2011–2020. *Source* ADF (2020a)

**Table 1** Saudi agricultural development fund: numbers of beneficiaries (loan receivers) for the period 2011—2020

| Years | Beneficiaries numbers |
|---|---|
| Average 2011–2015 | 3923 |
| 2016 | 3590 |
| 2017 | 4524 |
| 2018 | 4671 |
| 2019 | 2905 |
| 2020 | 3999 |

*Source* ADF (2020a)

projects in the vegetable sector, received loans number 464, representing (8.6%) of the number of loans approved for agricultural projects, with an estimated total value of about 0.75 billion US Dollars, representing (16%). In addition to dairy production, fish and shrimp farming, as well as date factories, refrigeration warehouses, and other specialized agricultural projects (ADF 2021).

Thirteen initiatives of ADF have been identified within the updated strategy of ADF (2021–2025). Seven of them are external initiatives, and six are internal ones. Details of their charters and objectives are as follows (ADF 2021):

(a) Provision of support to the local agricultural sector: this initiative will contribute to supporting local agricultural production following the directives of The National Agricultural Strategy. The objectives of this initiative are increasing the fund allocated to aquaculture, poultry production, and greenhouse to 364.67 million, 533.33 million, and 320 million US Dollars, respectively. However, only 21% were achieved by the end of 2021.

(b) Supporting the Sustainable Agricultural Rural Development Program: this initiative will contribute to the promotion of rural development by benefiting from comparative advantage. It provides financing credit services under the directives of and the initiatives of the Sustainable Agricultural Rural Development Program. The objectives of this initiative are to increase the fund allotted to development credits to 800 million US Dollars, however, only 11% were achieved.

(c) Support expansion across supply chains: Providing credit services to support agricultural input projects, transportation, handling, storage, processing and primary manufacturing, marketing, and distribution (especially marketing and exporting of dates). Raising loans to 30% of gross credit, yet only 13% were realized.

(d) Supporting agricultural investment abroad: this initiative will contribute to enhancing food security through the provision of financing credit services, in accordance with the directives and initiatives of the investment strategy responsible for abroad agricultural investment. The initiative aims to raise the fund allotted for abroad agricultural investment to 1466.67 million US Dollars, yet only 11% were attained.

(e) Encouraging the use of modern technologies, especially irrigation techniques: this initiative will provide finance to stimulate the use of modern technologies, especially irrigation techniques (in coordination with the General Irrigation Corporation and other concerned parties), in addition to, contributing to preserving natural resources and improving productivity. The objective of this initiative is to raise the fund allocated to the usage of modern technology to 756.27 million US Dollars, whereas, only 20% were attained.
(f) Developing a portfolio of services and activating partnerships: this initiative is concerned with the Development of credit products through cooperation with cooperative associations, partnerships with commercial banks, and activation of consultancy services through the approval of specialized companies. The objectives of this strategy are establishing a post of consulting and development and activation of services, establishing the post of partnerships, and activating partnerships. In addition to, activating new financing products in the agricultural sector. Yet, only 33% were realized.
(g) Develop customer-targeting methods and improve marketing effectiveness: the concern of this initiative is the development and implementation of the marketing plans and managing customer relations based on the proactive approach and collaboration with partners, use of digital channels to improve customer experience, and enhance operational effectiveness. The objectives of this initiative are to develop and implement a marketing strategy, develop and implement a digital customer experience strategy, and reach the level of 90% of customer satisfaction. It is worth noting that the achievement level is 50%. In addition to the other six initiatives that deal with the internal environment of the ADF.

Evidence showed that Saudi Arabia has reached a sustainable level of food security. It is also clear that KSA depends on three sources for sustaining its food security: local production, investment abroad, and imports. Pertaining the agricultural production, it shows a steady increase over time. For instance, fish production has increased from 30 thousand tons in 2015 to 110 thousand tons in 2021 (MEWA 2021). Likewise, self-satisfaction from poultry, table eggs, dairy, and red meat has increased from 40%, 110%, 100%, and 25% in 2015 to 66%, 112%, 121%, and 43% in 2021, respectively (MEWA 2021).

## *5.1 About Agricultural Development Fund*

The Saudi Arabian Agricultural Bank was established according to Royal Decree No. 58 dated 27 April 1963 as a governmental credit institution specialized in financing agricultural activity in the Kingdom to develop the agricultural sector through providing interest-free soft loans to farmers (ADF 2023a). On 26 January 2009, the Council of Ministers, after considering Shura (Senate) Council Resolution No. (106/71) dated 12/2/2008, approved the Agricultural Development Fund (ADF) regulations in the form attached to the resolution. Among the most prominent features of the regulations is that ADF replaces the Saudi Arabian Agricultural Bank, which has a capital of 5.33 billion US Dollars (ADF 2023a). It is noteworthy to mention here that, the ADF capital can be increased taking into account water conservation, the rationalization of its agricultural uses, and the preservation of the environment, however, it is subjected to the Council of Ministers approval. The ADF aims to support agricultural development and its sustainability by providing soft loans and the necessary credit facilities (ADF 2023a).

## *5.2 ADF Vision and Mission*

The ADF vision is "A leading fund that offers best-in-class sustainable financing solutions to promote the realization of the National Agriculture Strategy". Whereas, it is objectives are "Contribute to enhancing food security while preserving natural resources; Contribute to economic growth and promote sustainable agricultural rural development by building on regional comparative advantages; Provide best-in-class financing solutions and services by leveraging strategic partnerships; and Enhance financial sustainability, develop employee capabilities and achieve operational excellence within an established risk management framework (ADF 2023b; ADF 2021).

## *5.3 ADF Credit Services*

ADF classifies loans into four types: development loans, specialized projects loans, regular operating loans, and operating loans for specialized projects (ADF 2023c). Development loans are long-term agricultural loans that are granted directly to farmers to be used in the field of growing crops (fruit farms, apiaries), fishing boats, agricultural tourism, veterinary clinics and pharmacies, and vegetable carts (ADF 2023c). Specialized project loans are long-term credit granted directly to specialized projects for establishing new projects, expansion of existing ones, or rehabilitation of specialized projects. Obtaining this service requires an economic feasibility study and a license from the Ministry of Environment, Water and Agriculture. The repayment period is determined for specialized projects, based on cash flows, project studies, and credit analysis (ADF 2023c). Whereas, regular operating loans are short-term loans that are granted as direct loans for small enterprises to cover operating costs for one production cycle, and whose repayment period does not exceed one year. On the other hand, operating loans for specialized projects (agricultural products and projects) is one of the important services provided by the ADF, through which it provides an opportunity for the farmers to obtain a direct loan to finance working capital. It is a short-term credit service that covers the operating costs for one production cycle, the repayment period of which does not exceed two years (ADF 2023c).

## *5.4 Handling Troubled Projects Program*

The idea of this program is based on the reoperation of troubled projects in cooperation with both the Ministry of Environment, Water and Agriculture and investors who wish to invest in these projects (ADF 2023d).

### 5.4.1 Program Objectives

The objectives of handling the trouble project program are as follows (ADF 2023d):

(a) Treating the loans of troubled projects by offering those projects to new investors.
(b) Providing opportunities for new investors wishing to invest in the agricultural field.
(c) Restarting the troubled projects owned by ADF's borrowers.
(d) Contribute to the increment of the product in the local markets and reduce the supply and demand gap.
(e) Contribute to the development of the areas surrounding the establishment projects.

### 5.4.2 Possible Treatments for the Troubled Project According to the Status of Each Case

Generally, there are four types of project failures: financial, marketing, administrative, and technical (ADF 2023d). The possible treatments for the troubled project according to ADF (2023d) are rehabilitating the project, refinancing the project, scheduling installments of the defaulted debt, transferring the indebtedness to a new investor, leasing the project to an investor who wishes to invest without transferring ownership. In addition, entering the defaulter into a partnership with a new investor, and coordinating with the MEWA with regard to licenses such as changing the activity, and renewing the license.

## *5.5 The ADF Privacy Lending Policy*

This policy was developed to show how the Agricultural Development Fund collects, uses, and protects personal information provided by the borrower, based on the ADF's commitment to protecting the privacy of its customers and its keenness to achieve customers' benefit from using the Fund's website (ADF 2023e).

### 5.5.1 Collection and Uses of Customers' Personal Information

Customer's personal information that is willingly disclosed online during the provision of services is used to improve and activate the services they request. It is also used to complete and update the borrower's records and introduce them to other services; conduct research to improve ADF products, services, and technologies; follow up on requests and other services provided by the ADF website; in addition to, what is required by the authorities and applicable laws (ADF 2023e).

Pertaining to the disclosure of information: ADF has the right to disclose the collected information about the customers, services, traffic patterns of the ADF website and other information to its affiliates or other well-known parties to the extent permitted by laws and regulations, except the personal identity data, unless otherwise stated in the privacy policy. ADF can also disclose information that is required to be disclosed by law and/or that protects its legal rights (ADF 2023e).

Security protection of Information: the ADF website takes numerous measures (technical and security) to protect the security of customers' personal information from loss, misuse, mistreatment, modification, corruption, or destruction. All ADF employees are committed to follow a strict and comprehensive security policy that does not allow access to personal data Except for those authorized to do so and who are committed to preserving its confidential nature (ADF 2023e).

Links to other websites: the ADF gives a clear announcement to all ADF website users, which stated, "Please be aware when you use any link on the ADF website to direct you to another site, you might lose ADF privacy policy". ADF also advises visitors to first review the privacy policy of the website they want to browse before providing any personal identification information (ADF 2023e).

## *5.6 General Requirements for Accepting Applications for Credit Services*

The General requirements for accepting applications for credit services are (ADF 2023e):

(a) The minimum age for the ADS's clients (individuals) should not be less than 21 years.
(b) Applications for credit services provided to companies are accepted under the criteria for their official registration.
(c) The ADS's client applying for credit services is considered an independent financial liability, whose obligations towards the ADF are linked based on the credit services it receives.
(d) The application for obtaining credit services is accepted if the application is done through ADF's website or other approved channels.
(e) The ADF headquarter is specialized in studying loans for specialized agricultural projects, finalizing all procedures, and then disbursing loans and following them

up. It is also specialized in studying and approving development loans whose validity is greater than that of the branches.

(f) The ADF branches and offices are concerned with studying development loan applications, deciding on them, disbursing them, and following them up according to their validity.

(g) The ADF headquarters is concerned with studying all loans for its employees and loans for the first-degree relatives of branches and office managers, approving them, and following them up on their implementation.

(h) Submission of an estimated cost analysis of the investment.

(i) The guarantees are fulfilled in accordance with the indicators and practical risks mentioned in the financing and credit risks.

Credit services are provided by ADF based on the approved financing activities and in line with the requirements of credit finance risks on which the credit decision-making is based, taking into account the following (ADF 2023e):

(a) Acceptance of credit services is approved after fulfilling the basic requirements for each financing activity of the ADF's activities.

(b) Obtaining an acknowledgment and undertaking on the ADF's client, in the event of the expiration of the validity period specified for the technical examination, that the client be not entitled to a refund of the paid examination fees.

(c) The credit service application, which has passed the technical examination for more than one year for regular loans, and two years for loans for specialized projects, shall be canceled.

(d) The customer is notified at least twice within a year to complete the application procedures electronically.

(e) Collection of a new examination fee for the application from the ADF's client, after the statutory period prescribed for the technical examination has passed.

(f) In the event that the ADF's client submits a request to complete the credit service procedures, the technical examination will be repeated.

(g) Compliance with the technical requirements for credit services licensed by the Ministry of Environment, Water and Agriculture.

(h) The ADF's client is not entitled to sell, donate, assign, or lease the loaned areas without the Fund's approval.

(i) The customer is obligated to provide the Fund with any changes in the position of the credit services provided to him during the application submission, study, contract signing, disbursement, and payment stage.

(j) The ADF is obliged to clarify its position on providing the credit and the financing services that it supports, based on its strategy in the event that the customer applies for the credit service.

(k) The loan decision depends on the customer's creditworthiness and his/her ability to repay in the event of risks during implementation and operation.

(l) What applies to the ADF Saudi client applies to the foreign clients (independent investor or partner) for loans for Specialized Projects, if the documents and conditions of the foreign investor are met.

(m) The life span of the specialized projects is usually two years; the approval of these projects is subject to the submission of contracts and invoices.
(n) Follow-up and evaluation fees are refunded for the rest of the contract period if the ADF's client pays the full amount of the loan and during the validity period of the contract.

## *5.7 Lending Terms for Specialized Projects*

To be eligible for ADF funding, the following documents must be provided (ADF 2023e):

(a) An electronic version of an economic feasibility study that includes the technical specifications, as well as the financial and marketing analysis for the project.
(b) A ministerial license from both the Ministry of Environment, Water and Agriculture, and the Ministry of Commerce and Investment, along with a license from the municipality if the project site is located within an urban area.
(c) An agricultural record (registry) issued by the Ministry of Environment, Water and Agriculture. Fourthly, a copy of the national identity card, if the applicant is a Saudi citizen and
(d) The borrower must be at least 21 years old.
(e) Land ownership certificate, land lease (government lease) covering credit duration, and/or rent certificate covering the terms set by the ADF considering the following (ADF 2023e):

The evidence of the claim must comply with all legal procedures and regulations. Official documents issued by a notary public to divide a portion of the land described in a court-issued document, or a document obtained from another deed of transfer issued by a notary public, should ensure an understanding of the foundation on which it was built.

The lease agreement should be issued by a notary or a competent court, and be accompanied by a copy of the proof of ownership or a certificate that follows the legal procedures, proving ownership of the land on which the loan is requested for a minimum period of fifteen years, with the lessor's consent to mortgage the land in exchange for the loan.

A project land survey from an approved engineering office showing the coordinates is required.

(a) In case of the appointment of a legitimate agency under a power of attorney, the agency must meet the ADF's criteria, as outlined in the following text "The agent will have the authority to borrow from the Agricultural Development Fund and its branches in my name, sign the contract, receive loans, and sign any documents that require my presence at the Agricultural Development Fund. Additionally, the agent is expected to jointly assume responsibility with the guarantors for payment of the full amount before signing the contract, if it is borrowed.

(b) Evidence of the client's financial stability, such as bank account statements for the past six months, as well as proof of ownership of properties, real estate, or stock portfolios, must be submitted.
(c) Signing the acknowledgment form and agreeing to allow the inquiry of the customer's credit report through SIMAH.
(d) Copies of documents should be identical to the originals.
(e) ADF's client or their guarantors should pay all due installments in case of previous transactions with the Fund.
(f) Providing necessary guarantees, ensuring that the guarantors owe no standing debts to the fund.
(g) Payment of the examination fee.
(h) The submission of comprehensive engineering maps for the project.

### 5.7.1 Additional Terms

ADF has identified the following additional term for lending specialized projects (ADF 2023e):

(a) Projects that involve air-cooling greenhouses must provide a certificate from a licensed laboratory confirming the quality and quantity of water used in production. Alternatively, a certificate from the Ministry of Environment, Water and Agriculture stating the same information is required to be attached. Additionally, it is required that the project be located far away from any sources of pollution.
(b) All types of poultry projects must adhere to the distances specified by the Ministry of Environment, Water and Agriculture. Furthermore, for broiler chicken projects, a contract with a slaughterhouse needs to be submitted.
(c) Fattening projects involving calves must have insurance coverage. For corporate applications, the following documents must be submitted, each accompanied by a matching photograph: Memorandum of Association; Commercial registry; Annual budgets for existing companies and projects for the last three years; A list of the company's board members; A letter from the company's board of directors requesting a loan, along with authorization for the representative to review the fund and conclude the contract; Saudization certificate; A letter from the General Authority for Zakat and Income; A license issued by the General Authority for Investment for foreign companies, along with passport copies of non-Saudi partners. The conditions imposed by the General Authority for Investment or the relevant authority for foreign investors must also be met. For requests from cooperative societies, the following documents must be submitted, each with a copy and an identical original:

    (1) The last two minutes of the General Assembly meeting, The minutes of the meeting of the association's board of directors, including the loan application and authorization for the designated representative to review the application and sign the contract

(2) A copy of the association's bylaws and articles of incorporation - Association registration certificate from the Ministry of Labor and Social Affairs
(3) A statement of the association's capital and assets, including details of its activity in the previous period
(4) A letter of endorsement from the Ministry of Environment, Water and Agriculture and the Council of Cooperative Societies
(5) The last three budgets were approved by an accounting office.

Lending Terms for Short-Term Specialized Projects

The eligibility for a short-term loan for specialized projects required the farmer/investor to (ADF 2023e):

(a) Obtain a license from the MEWA and the Ministry of Commerce and Investment for the establishment of the project. Farmers/investors must also submit a license from the municipality, in case the project is located within an urban area.
(b) Obtain an agricultural registry from the MEWA.
(c) Provide a copy of the national identity card, if the farmer/investor is a Saudi citizen.
(d) The borrower must be at least twenty-one years old.
(e) Provide the land possession certificate, ownership deed, or a government lease contract that aligns with the financing term. The lease contract should include the terms of the funding agreement. It is important to note that the following conditions must be met: Proof of ownership should comply with all legal procedures. A court or another official deed to validate the transfer of ownership must verify any land deeds issued by a notary public. The basis on which the project was built must be established. A notary public or a competent court must issue the lease contract. It should be accompanied by a true copy of the proof of ownership of the land on which the loan is requested, which should have been in the applicant's possession for at least fifteen years. Additionally, the land leaseholder must approve the mortgage of the land in exchange for the loan.
(f) Provide a survey of the project land conducted by an approved engineering office, showing the coordinates.
(g) If there is a power of attorney in place, ensure that it complies with the ADF's conditions. The agent has the authority to borrow from the ADF and its branches on behalf of the applicant. They can sign contracts, receive loans, waive and receive loans, and perform any actions that require the applicant's presence at the Agricultural Development Fund. The agent is also responsible for jointly paying the full loan amount with the guarantors before signing the contract.
(h) Submit copies of all necessary documents, which should be identical to the original copies issued by the relevant authorities or the Fund.
(i) If there have been previous dealings with the ADF, ensure that the installments on the loan requested from the applicant or their guarantors have been paid.

(j) Provide the necessary guarantees, ensuring that there are no outstanding dues to the fund from the guarantors.
(k) Submit proof of the client's financial stability, such as a bank statement for the last six months, property ownership documents, real estate holdings, or stock portfolios.
(l) Sign the acknowledgment form and agree to allow the inquiry of the client's credit report through SIMAH.
(m) Pay the examination fee.

Lending Terms for Corporate Company Applications

The investor/s must provide a copy of each of the following, along with original documents (ADF 2023e):

(a) Memorandum of Association.
(b) Commercial registry.
(c) The last three annual budgets for existing companies and projects.
(d) A list of the company's board members.
(e) A letter from the company's board of directors, requesting a loan and authorizing the representative to review the funds and finalize the contract.
(f) Saudization certificate.
(g) A letter from the General Authority for Zakat and Income.
(h) A license to practice the activity is issued by the General Authority for Investment for foreign companies. Passport copies of non-Saudi partners should accompany this. The conditions that apply to the foreign investor apply to non-Saudi partners, as issued by the General Authority for Investment or the relevant authority.

Lending Terms for Cooperative Associations

To complete the application for ADF loans, it is necessary to provide a copy of each of the following, along with original documents (ADF 2023e):

(a) The last two minutes of the General Assembly meeting.
(b) The minutes of the association's board of directors' meeting, including the loan application and the authorization of the individual representing the association's members to review the application and sign the contract.
(c) A copy of the association's bylaws, articles of incorporation, and bylaws.
(d) The association's registration certificate at the Ministry of Labor and Social Affairs.
(e) A statement of the association's capital and assets, including an explanation of its activity in the previous period.
(f) A letter of endorsement from the Ministry of Environment, Water, and Agriculture, as well as the Council of Cooperative Societies.
(g) The last three budgets were approved by an accounting office.

Lending Terms for Financing Indirect Capital

The lending conditions for financing indirect capital are as follows (ADF 2023e): farmer/investor should fill out the application form, explaining the required credit facilities and the purpose; provide a comprehensive overview of the activity that requires funding and signing the acknowledgment form and undertaking to agree to inquire about the customer's credit report through SIMAH. If the applicant is a Saudi citizen, he/she must include a copy of his/her national identity card. Additionally, a commercial registry indicating the activity to be financed is necessary.

## *5.8 Guarantee for Credit Services*

The guarantee for credit services is the last three annual budgets for established companies and projects; the prices offered or an unpaid invoice with details for the imported product; the contract agreements with suppliers and local distributors for the distribution of the product, if applicable. In addition to, other conditions in the general requirements for credit services, such as: before considering any credit service request, the existing debts of troubled companies will be addressed, especially if a partner with ownership exceeding 5% applies for credit, besides, calculating fixed costs for long-term investment credit services based on price quotes, signed contracts, and invoices. This excludes costs related to buildings and operations, which will be determined according to the lending rates, set by the Fund.

The lending areas for long-term investment credit services cover all investment costs of the project, including its different components. The stage of applying for development loans involves the ADFs client acknowledging and accepting the inquiry from the Saudi Credit Bureau, SIMAH. Additionally, the client must submit their national identity documents and official records. If necessary, the client should also provide licenses related to their business activities. It is also required to submit an Official Authorization Letter, which grants the agent the authority to borrow from the Fund in the owner's name; sign contracts, receive loans, and the right to waive and sign any necessary documents on behalf of the owner, as required by the Fund.

## *5.9 The ADF's Client Land Ownership Deed*

The ADF's client must provide a land ownership deed that meets all legal requirements for the land on which the loan is being requested. This deed could be issued by a notary public and should confirm the boundaries set by a court-issued deed or another valid deed. It is important to ensure that the land was built on a legitimate basis, through either proper legal procedures or an order from a notary or regulations and instructions. If the original deed is lost or damaged, a replacement attested by the court or notary public must be presented. The original title deeds must be shown in all cases. When applying for a new loan, the notary-issued documents must be up-to-date electronic deeds. Additionally, a distribution decision from the Ministry of Environment, Water, and Agriculture, as well as temporary documents according to Circular No. 2755 dated 5/2/2016, are required.

### 5.9.1 Government Lease

The client of the fund provides guarantees for credit services, along with proof of creditworthiness. The stage involves applying for credit services to finance working capital for operational development loans. The client of the fund acknowledges and undertakes to approve the inquiry from Saudi Credit Bureau, SIMAH. The client of the fund submits national identity documents and official records. It is necessary to be a legitimate agency (official authorization) that includes the agent's right to borrow from the fund in the owner's name, the right to sign the contract, receive loans, and the right to waive and sign anything that requires the agent's presence in the fund (ADF 2023f).

The client of the ADF must submit a land ownership deed that meets all legal procedures and requirements for the land on which the loan is being requested. This includes deeds issued by a notary public to empty a portion of a land described in a deed issued by the court, or a deed emptied from another deed issued by a notary public. It is important to determine the basis on which the land was built, whether it was based on consolidation fulfilling all legal procedures or on the discharge of a notary public, or an order granted by regulations and instructions. Lending can be done without objection if it is done in accordance with a statement issued by the notary public or the court issuing the deed. If the deed presented to the fund is a replacement for a lost deed, the court or notary public must attest it. The lease contract must comply with Circular No. 946/T/5 dated 9/2/2009. In all cases, title deeds must be examined. A distribution decision issued by the Ministry of Environment, Water and Agriculture, temporary documents according to Circular No. 2755 dated 5/2/2006, and a government lease are required. The client of the fund must provide guarantees for credit services and proof of creditworthiness (ADF 2023f).

### 5.9.2 Abroad Investment

The Abroad Agricultural Investment Program aims to expand and secure various foreign sources of food supplies. This program is part of the Kingdom's initiative to ensure food security through investing abroad. The loan duration is 10 years, with a grace period of two years. Loans are usually given in either Saudi riyals or US dollars. The Agricultural Development Fund can contribute up to a maximum of 60% of the project's total cost. Repayment of the loan will vary for each project, depending on the nature of its cash flow (ADF 2023f).

The following types of guarantees are usually required by ADF for abroad investment (ADF 2023f):

(a) Bank Collateral: submission of bank collateral covering 100% of the total loans,
(b) Mortgage of institutional or personal investments to another party (such as cash deposit, stocks, bonds, and commodities),
(c) Project assets including stocks,
(d) Personal real estate assets owned by another party,
(e) Insurance licensing: transfer of various insurance certificates,
(f) The company's assets in the Kingdom, and
(g) Legal guarantee: full value of the insurance and the wages are according to the insurance policy. It is worth noting that, the ADF provides funds for the production of the following crops: Basic crops: wheat, maize, and green fodder, and secondary crops: red meat, barley, rice, edible oil, sugar, and soya beans.

The required documents for the abroad investment loans are as follows (ADF 2023f):

(a) Company profile, project description, and investor background,
(b) An official letter with a request to facilitate the ADF site from the authorized person,
(c) The company's commercial registry in the KSA,
(d) The license/commercial registration required from the company to operate in the country where the project is located,
(e) The audited financial statements of the company for the last 3 years in Saudi Arabia,
(f) Feasibility study in English. In addition to:
(g) A title deed for the project land or a lease contract,
(h) The project design and outline,
(i) List of the bank credit facilities enjoyed by the company,
(j) Proposed documents and guarantees,
(k) A list of related projects implemented previously by the company,
(l) Financing requirements [(a) amount of financing (b) purpose of financing (new project, expansion of an existing project, (c) refinancing of an existing project, provided that the project's life does not exceed two years],
(m) Product Sales Agreement and Marketing Plan, and
(n) Prices offered by the executing companies or invoices for the executed works.

Eligibilities for the investors and projects are as follows: for the investors: more than 50% of Saudi companies of all kinds should be owned by a Saudi entity/person, have a registered entity in the KSA, have experience with agribusiness in Saudi investment abroad in addition to the technical capabilities of the team. Whereas, for the projects are: funding includes new projects and expansion, the maximum contribution of ADF's not exceed 60% of the project cost, the optimal loan ranges between 30 and 75 million US dollars, exporting at least 50% of the production to KSA (to achieve food security for both the Kingdom and the host country), and economic feasibility study.

## 6 Conclusion and Prospects

Agricultural finance is the fundamental tool used for sustaining food security, as it affects both the supply (food availability) and demand side (food accessibility) of food. It affects the food availability (production) pillar of food security through the provision of the right quantity and quality of input, enhancement of agricultural operation and harvest, in addition to facilitating the marketing of agricultural output. Whereas, it directly affects food accessibility through the provision of funds and indirectly through the income generated from the invested loans. In this context, the ADF contributes substantially to achieving food security in the Kingdom. The total numbers and values of the distributed loans since the inauguration of the ADF until the end of the fiscal year 2021 are 124,786 and 14.67 billion US Dollars, respectively. Moreover, ADF usually liaises with MEWA in achieving food security through the provision of support and credit to agricultural investors. It is very clear that ADF has set many initiatives for achieving Vision 2030, which seeks, among others, to achieve sustainable levels of food security. Evidence showed that Saudi Arabia has reached a stable level of food security. ADF is playing a vital role in the provision of the necessary funds for local and abroad investment, in addition to imports.

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# Chapter 9
# Food Security Under Climate Change Scenario in Saudi Arabia

**Abdulrahman M. Almadini**

**Abstract** Climate change and food security nowadays are global major issues due to their direct and indirect impacts on humans' lives and their daily life affairs. Thus, these impacts have stimulated several organizations and authorities at all levels to seriously consider such issues in their deliberations and decisions in a way or another. In line with such widespread concerns, the Saudi authorities have also decisively taken these issues into considerations in the country's 2030 strategic vision that was announced in detail on 25 April 2016 by the Royal Crown Prince Mohammad bin Salman. Among the major objectives of the 2030 Saudi vision is to carry full responsibilities towards the participation in combating negative impacts of climate change on local and international levels as well as the achievement of the national food security. This chapter therefore is intended to shed lights on the situations of both climate change and food security in the Kingdom of Saudi Arabia. It is therefore this chapter aims to thoroughly discuss food security under climate change scenario in the KSA. The chapter is structured to provide some general perspectives on the KSA and its agricultural sector, food security and its status in KSA, and climate change including specific thoughts on its situations and future expectations and its impact on the food security in Saudi Arabia.

**Keywords** Climate change · Food security · Agricultural products · Natural resources · 2030 vision · Saudi Arabia

## 1 Introduction

Respective international and national organizations and authorities at all levels have exhibited prime concerns considering climate change and food security issues in their discussions and hence decisions. This is due to the impacts of both issues on the lives of humans and the surrounding environment and its components. As reported

A. M. Almadini (✉)
Department of Agricultural Environment and Natural Resources, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: almadiniam@gmail.com



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by several worldwide agencies and scientific studies, climate change refers to the temporal alterations in the compositions of the global atmosphere that occurred over consecutive decades due to human's activities (deforestation, desertification, emission of greenhouse gases, etc.) and/or natural incidents (volcanic activities, earthquakes, etc.) (IPCC 2007; Ishaq-ur-Rahman 2013; UNFCCC 1992; Werndl 2016). Meanwhile, food security refers to the physical and economic accessibility of sufficient, safe, and nutritious foods that provide dietary needs and always meet food preferences for an active and healthy life of all people (FAO 1996). The definition of food security has gone through several revisions since its first-time introduction in 1974 till it has been settled on six pillars deciding the food security dimensions. These pillars include food's availability, accessibility, stability, utilization, agency, and sustainability (Barrett 2010; Clapp et al. 2015, 2022; Engler-Stringer 2014; FAO 1992, 2006).

Food security is chiefly planned to prevent hunger and malnutrition, which are essential issues defying the Sustainable Development Goals of the United Nations aiming to end both "poverty" and "hunger" (UN 2023). World Food Program reported that the magnitude of current hunger and malnutrition catastrophe in the World is formidable with 345.2 million people anticipated to be vulnerable to food insecurity in the year of 2023, an ascended number of more than two folds from the year of 2020 (WFP 2023). Agricultural productions form a pivotal source of food products to feed the drastically mounting World's population ensuring food security (Angelo 2017; Fakhri 2020; Pretty et al. 1996; Smutka et al. 2009). However, changes in the climate demonstrate prime negative impacts on agricultural activities and hence food products (Auffhammer et al. 2012; Liaqat et al. 2022; Lin et al. 2020; Nelson et al. 2009; Sinnarong et al. 2022). This implies that these impacts of climate change on agricultural productions will also affect food security attainment, denoting the interrelationships between both issues of climate change and food security.

Moreover, the Saudi authorities have also convincingly considered these issues of climate change and food security in the country's 2030 strategic vision (Vision2030 2023). This strategic vision includes various attainable objectives, among which are to meet all obligations towards combatting the negative impacts of climate change on local and international levels as well as to attain the national food security promoting the KSA to reach to a zero-hunger condition granting better life for everybody living in it. The KSA is a vast country with a marked location at the southwestern corner of the Asian continent and a distinctive geographical structure featured with diverse topographies (Al-Khatib 1974; Al-Nashwan 2011; Alwelaie 2008; GASTAT 2022; SGS 2022).

Generally, the Kingdom has of a tropical and subtropical desert climate with high temperatures in daytime and low ones in nighttime coincided with dearth rainfall (NMC 2022). Also, the country has a wide range of diverse wildlife, including desert rangelands, forestlands, and wetlands (Abu Zinada et al. 2001; Aref and EL-Juhany 2000; El-Juhany and Aref 2012, 2013). Considering these features, the Saudi government has been generously managing all efforts supporting the country to achieve the objectives of its 2030 strategic vision, which allowed it to successfully attain numerous achievements related to the climate change and food security issues.

It is therefore this chapter is intended to thoroughly discuss food security under climate change scenario in the KSA. The chapter is structured to provide some general insights on the KSA and its agricultural sector, food security and its status in KSA, and climate change including specific thoughts on its situations and future expectations and its impact on the food security in the KSA.

## 2 Kingdom of Saudi Arabia (KSA)

### *2.1 Location*

The Kingdom of Saudi Arabia (KSA) is a huge country being distinctively located at the southwestern corner of the Asian continent between the latitudes of 16° 17′ and 32° 14′ N and the longitudes of 34° 29′ and 55° 40′ E, with the Tropical of Cancer line (23.5°) crossing the country almost in the middle passing through some important cities and districts (Al-Nashwan 2011). The KSA covers four fifth of the Arabian Peninsula with an area of about 2.15 million sq. km (830,000 sq. mile). The location of the Peninsula has a historical importance, as it is situated between the Asian continent in the east and the African continent in the west, which granted a distinct value to the location of KSA (Al-Khatib 1974; Al-Nashwan 2011; GASTAT 2022). Figure 1 shows the general map, geographical location, and borders of the KSA.

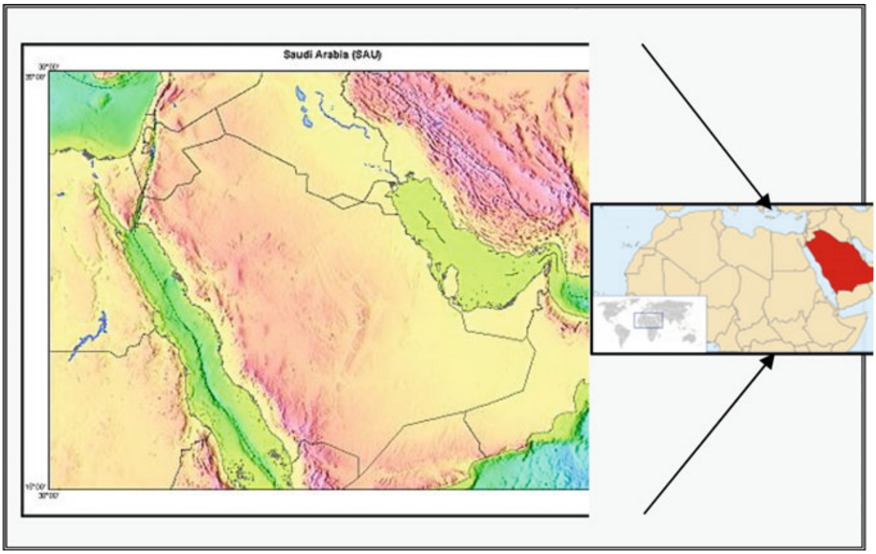



**Fig. 1** The general map, geographical location, and borders of the Kingdom of Saudi Arabia (https://en.wikipedia.org/wiki/Geography_of_Saudi_Arabia)

The KSA is bordered in the west by the Red Sea and the Gulf of Aqaba (1800 km); in the east by the Arabian Gulf (1050 km), United Arab Emirates (457 km), and Qatar (60 km); in the north by Kuwait (222 km), Iraq (814 km), and Jordan (728 km); and in the south by Yemen (1458 km) and Oman (676 km) (Al-Khatib 1974; Al-Nashwan 2011).

## 2.2 Population

According to the 2020 mid-year census (GASTAT 2022), the total population of KSA is more than 35 million, with almost 38% non-Saudis. The gender statistics of the Saudis indicates that there are 57.78% males and 42.22% females. Statistical data have also indicated that 36.7% of the KSA's populations are young with an age of 15–34 years, as compared with 30.3% of age 0–14 years (children) and 33% older than 35 years (GASTAT 2020).

According to the third quarter of 2021 statistics (GASTAT 2021), the employments among the Saudis are 60.8% males and 21.8% females. Unified National Platform (UNP 2022) indicated that the major workforces of the Saudi citizens are divided into three sectors, which are as follows: the service (28.69%), the technical and scientific (27.98), and the administrative (3.56%), with majority of females working in the technical and scientific sector. It was also indicated that more than two-thirds of this Saudi workforce are aged between 25 and 44 years, with 67.5% males and 77.0% females. In addition, it has been revealed that 96.5% of the Saudi workforces are educated, with 99.1% males and 98.5% females (UNP 2022).

## 2.3 Geographic Features

The KSA has a distinctive geographic structure that has assured the country diverse topographical features. Such features are evolved from the vertical and horizontal earth movements as well as the climatic conditions of wet and dry events occurred during the past geologic era (Al-Nashwan 2011; Al-Khatib 1974; Alwelaie 2008; GASTAT 2022; SGS 2022). The KSA geography generally consists of huge and tall mountains in the west that drop abruptly westward to the coastal plain by the Red Sea and tilt down gently eastwards toward the inlands of the country as shown in Fig. 2, which outlines the general geographical features of KSA.

In brief, these geographic features of the KSA commence in the western part of the country with the "Tihama" coastal plain that lies along the Red Sea and the Gulf of Aqaba. The width of this plain is narrow in the north by the Gulf of Aqaba and becomes wider to reach its maximum distance (60 km) near Jazan province in the south. Then, parallel to this coastal plain in the east lies a string of the "Sarawat" mountains (the Western Highlands) that extends from the north by the Gulf of Aqaba to the Saudi-Yemeni border in the south, with a width ranging from 40 to 140 km.


**Fig. 2** The general geographical features of Kingdom of Saudi Arabia (http://bkanegawsaudiarabia.weebly.com/geography-and-environment.html)

These mountains also vary in their elevations that generally ascent from north to south, being mainly formed from plutonic, magnetic, and metamorphic rocks during the pre-Cambrian age. These Highlands however are divided into two major divisions of mountains at the southern vicinity of the Holy city "Mecca" (Al-Khatib 1974; Al-Nashwan 2011; Alwelaie 2008; GASTAT 2022; SGS 2022).

The southern division of these mountains is the "Asir" mountains that are formed on narrow belt with an average of 50 m wide, yet certain areas extend to about 140 km. These mountains vary in their altitudes from 1400 m above the sea level to the highest point in the county at the "Al-Soudah" mountain (3207 m high) that is located north-western of "Abha" city in Asir province. These mountains have several wadis (valleys) inclining eastward (Najran valley, Bishah valley, and Trubah valley) and westward (Jazan valley, Bisha valley, Hally valley, and Yabbah valley). Moreover, the northern division of these mountains is the "Hijaz" mountains that start from the lowland located in the southern vicinity of holy city "Mecca" to the north by the Gulf of Aqaba. The two holy cities of "Mecca", that includes the holey "Al-Haram Mosque", and "Al-Madina Al-Monwara", the city of the Prophet Mohammad peace and blessing of Allah upon him, are found in this division. In the north of Al-Madeia Al-Monwara, the width of these mountains reaches to 140 km. There are some famous valleys in these mountains known as the "western valleys" that discharge into the Red Sea. These valleys include "Al-Himdh" valley, "Fatimah" valley, "Kudiad" valley, "Alqahah" valley, "Al-Safra" valley, "Al-Hamd" valley, and "Al-Jezl" valley. In some locations, these mountains detach from each other; and they usually are less rugged and considerably drier than those mountains of the southern division. Also, several "Harret" (lava field) are being scattered in the northern mountains' region.

East of this string of mountains comes the “Plateau of Najd” that stretches eastward to “Samman” desert and “Dahnaa” dune desert and southward to the “Wadi Al-Dwassir”. This Plateau is north of the “Empty Quarter” desert and extends northward to the “Najd” plain to connect with the “Great Nafud” desert, and then to the borders of Iraq and Jordan. The altitude of this plateau ranges from 1500 in the west to 600 m in the east above the sea level. In this Plateau, there are some famous mountains, among which are the “Tuwaiq” mountain ($\approx$ 1000 km long) in Riyadh province and the mountains of “Aja” ($\approx$ 100 km long and 20–30 km wide) and “Salmah” ($\approx$ 60 km long and 10–15 wide) in Hail province. Several eminent valleys are also available in this plateau, including “Wadi Hanifah”, “Wadi Al-Rimah”, “Wadi Al- Dawasir”, “Wadi Al-Batin” and others (Al-Khatib 1974; Al-Nashwan 2011; Alwelaie 2008; GASTAT 2022; SGS 2022).

East of the “Najd Plateau” is the eastern coastal plain of the “Arabian Gulf” that extends for 1000 km from the Kuwaiti-Saudi border in the north and the Saudi borders with States of Qatari and United Arab Emirates. The plain is primarily confined between the “Saman Platea” in the west and the Arabian Gulf in the east. The width of this plain varies from 60 km in the north to 130 km west of “Dammam” city that is sited on the western coast of the Arabian Gulf. The elevation of the plain slowly inclines from west to east at a rate of 1 m/km. One of its notable features is its rocks that consist of sea and continental sediments, causing widely scattered salt paddies particularly near the salty water of the Gulf (Al-Khatib 1974; Al-Nashwan 2011; Alwelaie 2008; GASTAT 2022; SGS 2022).

Most of the KSA land surface (about 50%) is covered by four main deserts of shifting sand-dunes, which is one of the distinctive features of the KSA topography (Al-Nashwan 2011; Alwelaie 2008; GASTAT 2022). This is due to the position of the country within the vast belt of the tropical desert that stretches from the “Atlantic Ocean” in the west to the “Thar Desert” in the eastern India (Fig. 3). The prime features of the four major deserts in the KSA are as follows:

1. The desert of “Rub Al-Khali” that is considered one of the global largest sand dune deserts, being situated in the southern and south-eastern part of the country with 1200 km length from east to west and 640 m width from north to south to cover an area of 650,000 sq. km. Some sand dunes in this desert reach a height of about 250 m. The types of sand dunes in the “Rub Al-Khali” desert include moving crescent-shaped barchan, longitudinal dunes more than 160 km long, and enormous dunes rising to an elevation of 300 m in the east, whilst elevation reaches about 600 m in the west with fine and soft sands.
2. The desert of “Great Nafud”, which is located in the northern part of the country, covering an area of 64,630 sq. km, with 342 km length from east to west and 275 km width from north to south. It has lengthy longitudinal dunes that are as high as 900 m in both south and west that are separated by valleys up to 16 km wide.


**Fig. 3** The vast belt of the tropical desert (https://www.google.com/)

3. The desert of "Dahna" that connects the former two in a sand body arc-shape. This desert is almost 1448 km long and 48 km wide, with an area about 40,789 sq km. Its southern portion takes a westward arc shape following the "Jabal Tuwaiq". It is also extended northward from the Rub Al-Khali desert to end up in the Arabian Gulf.
4. The desert of "Al-Jafurah" that is considered as an extension of the "Rub Al-Khali" desert. Its location is in the eastern part of the KSA between the "Arab Gulf" in the east, "Al-Saman Plateau" in the west, and "Rub Al-Khali" in the south, with an average of width about 100 km being wider in the south than in the north. Figure 4 demonstrates the distributions of these major four deserts in the country and their connection to each other (Al-Shaye et al. 2020).

## *2.4 Climate*

The vast area of the KSA generally has a desert climate with extreme heat and aridity, characterized the country by its tropical and subtropical desert climate features, with high temperatures in daytimes and low ones in nighttime that were coinciding with a dearth rainfall, except in the southwestern area (NCM 2022). Most of the Kingdom usually receives scanty quantities of rain in winter and spring. Yet, the rainfall in the southwestern highlands is comparatively substantial and occurs in the summer season, as it is affected by the southwest monsoon (Al-Blehed 1975). Air humidity also varies from high in the coastal areas and mountains and be lower going inlands. According to the Köppen-Geiger Climatic Classification, the subtype of the KSA climate is "BWh" that is defined as an arid to a desert hot arid one (Fig. 5).


**Fig. 4** The distributions of the major four deserts in the KSA (Al-Shaye et al. 2020)

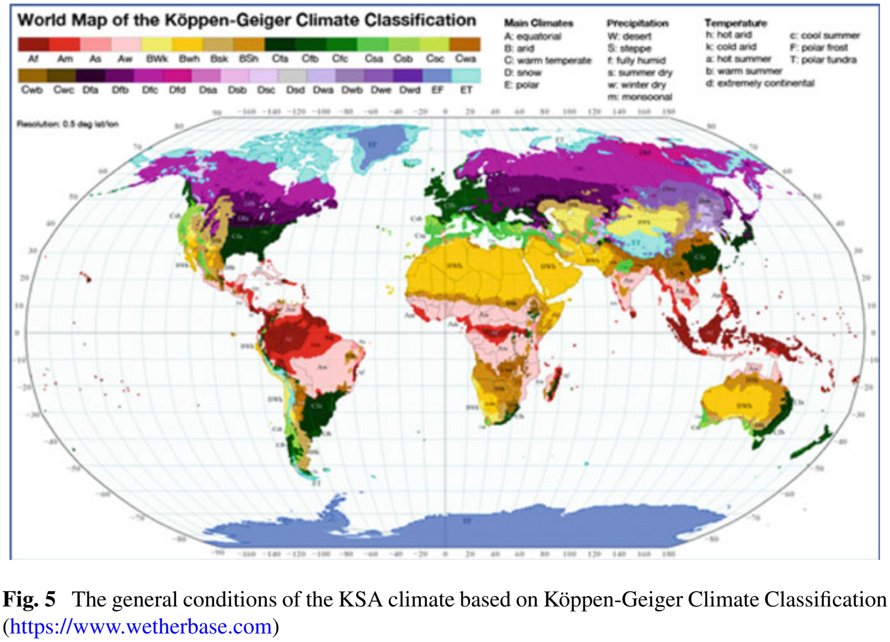



**Fig. 5** The general conditions of the KSA climate based on Köppen-Geiger Climate Classification (https://www.wetherbase.com)

Specifically speaking, it is significant to identify that there are several factors determining the conditions of the climate in any region (Nikolov and Petrov 2014; Stevens 2011). Among which are the latitude referring to the specific position to the north and south lines on the Earth, the elevation according to the sea level, the proximate distance to water bodies and their efficiency in supplying humidity, the geographic position on the Earth, the natural topography, the atmospheric circulation, and the biogeography. As indicated earlier, the KSA is located north of the Equator with the Tropical of Cancer (23.5°) passes through its middle and it has diverse topographic features. It is therefore the climate of the Kingdom is markedly different from one region to another.

Such climatic variations in the Kingdom have been thoroughly illustrated by the National Center of Metrology (NCM) using collected monthly climatic data for 34 years (1985–2019) from various weather stations allocated all over the country (NCM 2022). These data include the patterns of rainfall averages (Fig. 6), temperatures various parameters for values of average (Fig. 7a), maximum (Fig. 7b), and minimum (Fig. 7c), the average of pressure at the sea level (Fig. 8), wind directions (Fig. 9), humidity (Fig. 10), and climate classification (Fig. 11). These figures were selected for the months of March, June, September, and December, which were particularly chosen to represent the variations in seasonal circumstances. Also, the NCM (2022) has calculated the spatial precipitation index (SPI) to monitor the drought condition in the country. Figure 12 presents the SPI for the year of 2019, as an example. Table 1 summaries the key values for the SPI index (NCM 2022).

All outlined climatic data verify the differences in the climatic conditions in the KSA from a region to another. Thus, it is possibly to conclude that there are three different climatic regions, which are the southern and southwestern being affected by the Equatorial climate, the northern and northwestern being affected by the Mediterranean climate and the central and eastern parts of the country being under desert dominated climate. EL-Sabbagh (1982) suggested that there are three climatic regions and several subregions for the KSA on basis of the main climate features observed over the country. Therefore, these variations in the climate conditions in the KSA ought to be carefully considered in planning the farming activities in the country to attain the objected food security.

It is therefore necessary to emphasize that the above-mentioned climatic parameters particularly as the high temperature degrees and the meager rainfall levels as well as the extreme evaporation rates have necessitated the agricultural sector in the Kingdom to generally depend on irrigation practices that principally use water from underground sources, as will be discussed later. Thus, it is suggested that these climatic data ought to be carefully considered in discussing the subject of the national food security and the climate change.

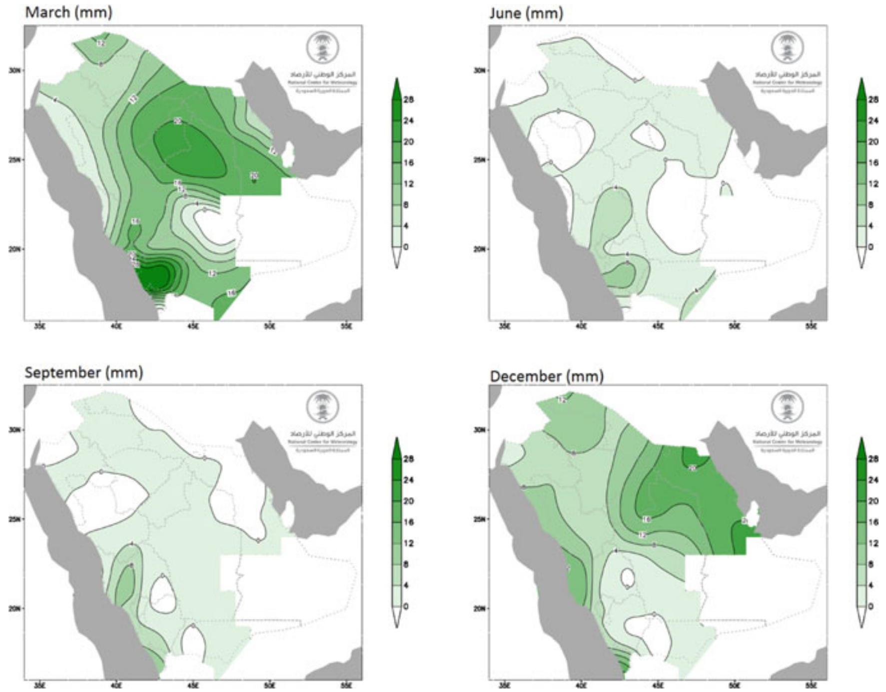



**Fig. 6** The patterns of rainfall averages in the KSA for the period from 1985 to 2019

## 2.5 *National Related Agricultural Resources*

### 2.5.1 Natural Resources

The KSA is a wealthy country of natural resources that comprise a wide range of diverse wildlife. These resources include desert rangelands, forestlands, and wetlands. Desert rangelands are widespread in the country, covering about 79% ($1.7 \times 10^6$ sq km$^2$) of the $2.15 \times 10^6$ sq km$^2$ country's total area (Abu Zinada et al. 2001). Also, there are areas of forestlands that are relatively small (27,000 sq km$^2$, ≈ 1.26%) (Aref and EL-Juhany 2000; El-Juhany and Aref 2012, 2013), yet they present an immense value. These forestlands are mainly sited along the Sarawat mountains in the western part of the country. Furthermore, the KSA wetland resources in present time are short of precise quantitative data regarding their overall status and trends (Al-Obaid et al. 2017). Yet, wide natural varieties of wetlands exist in the country despite of its topographic features and dominant arid climate as stated by Newton (1995), who has also added that there are eight identified wetland systems, namely: coastal, dune-field, sabkha, karats, mountain, geothermal, wadi, and man-made. Some of these wetlands are formed via water ponds and valley streams after season rainfall, agricultural drainage water or/and treated sewage water (Abd-El-Gawad et al. 2021;

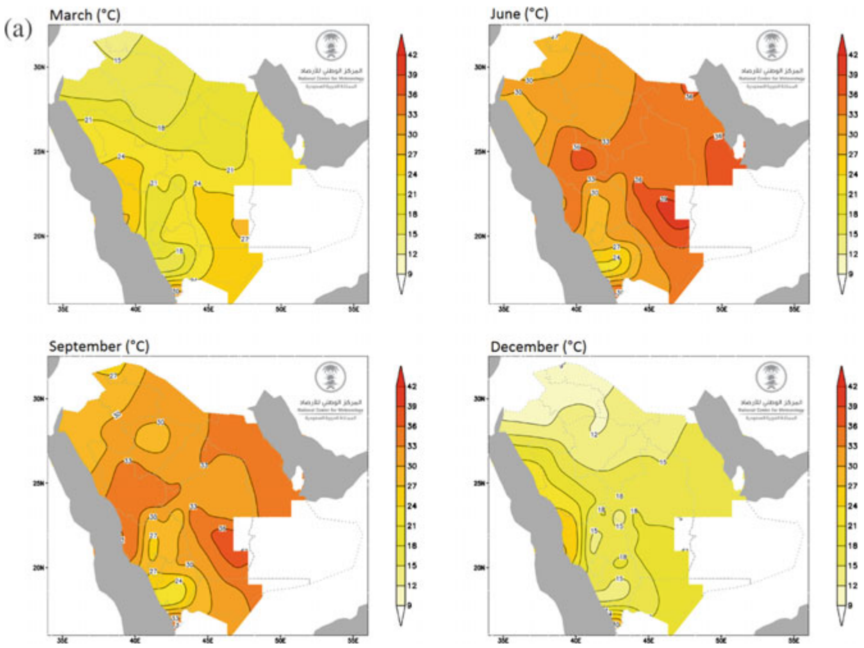



**Fig. 7** **a** The patterns of temperature averages in the KSA for the period from 1985 to 2019. **b** The patterns of maximum temperatures in the KSA for the period from 1985 to 2019. **c** The patterns of minimum temperatures in the KSA for the period from 1985 to 2019

Al-Amro et al. 2018; Al-Hammad and Abd El-Salam 2017; Al-Johany et al. 2014; Al-Qahtani and Al-Johany 2018; El Mahmoudi et al. 2009; Gala et al. 2021).

These areas of natural resources though are rich biodiverse ecosystems with a wide spectrum of flora (Abd-El-Gawad et al. 2021; Alatar et al. 2012; Alhaithloul 2014; Al Mutairi et al. 2012; Al-Rowaily et al. 2018, 2020; Alshahrani 2021; Daur 2012; El-Sheikh et al. 2013, 2017) and fauna (Abdel-Dayem et al. 2015, 2019; Abu El-Ghiet et al. 2021; Cunningham 2010; Cunningham and Wacher 2009; Cunningham and Wronski 2010, 2011; El-Hawagry et al. 2016; Hall et al. 2010; Judas et al. 2006; Paray and Al-Sadoon 2018). They vitally serve multi-functions such as: providing foods for humans, livestock's feeds, recreational areas as well as supporting climate and environmental stability (Al-Obaid et al. 2017; Al-Tokhais and Thapa 2019; Barichievy et al. 2018; Sayre et al. 2012).

However, these ecosystems are commonly in a state of disequilibrium, because of the rainfall scarcity. They also suffer from various threating factors as overgrazing, overcutting woody plants, severe environmental conditions, off-road tracks, and other human activities (Al-Rowaily 1999; Al-Rowaily et al. 2012, 2015; AL-Ghumaiz 2016; Al-Mutairi et al. 2015; Assaeed et al. 2019; El-Sheikh et al. 2019; Jamil et al. 2022).

Therefore, the Saudi government has instituted the National Commission for Wildlife Conservation and Development (NCWCD) in the Riyadh city by the Royal

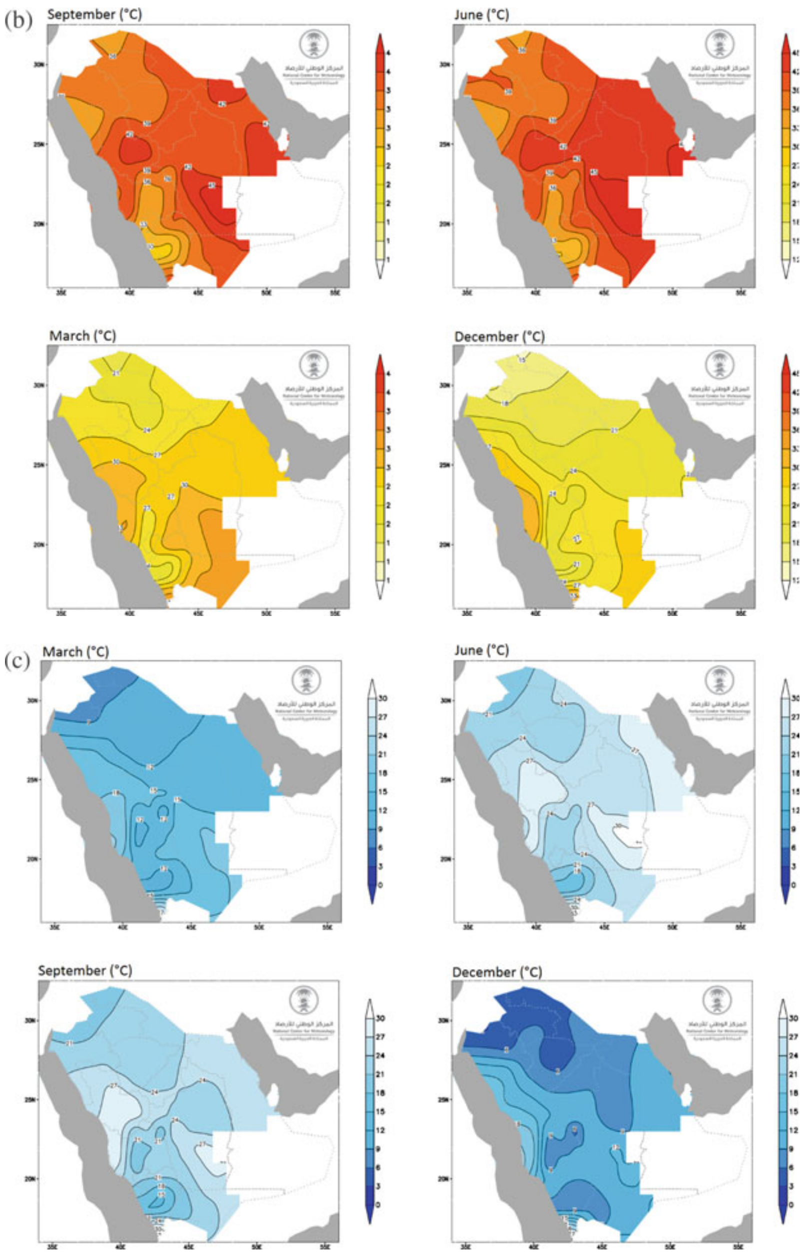



**Fig. 7** (continued)

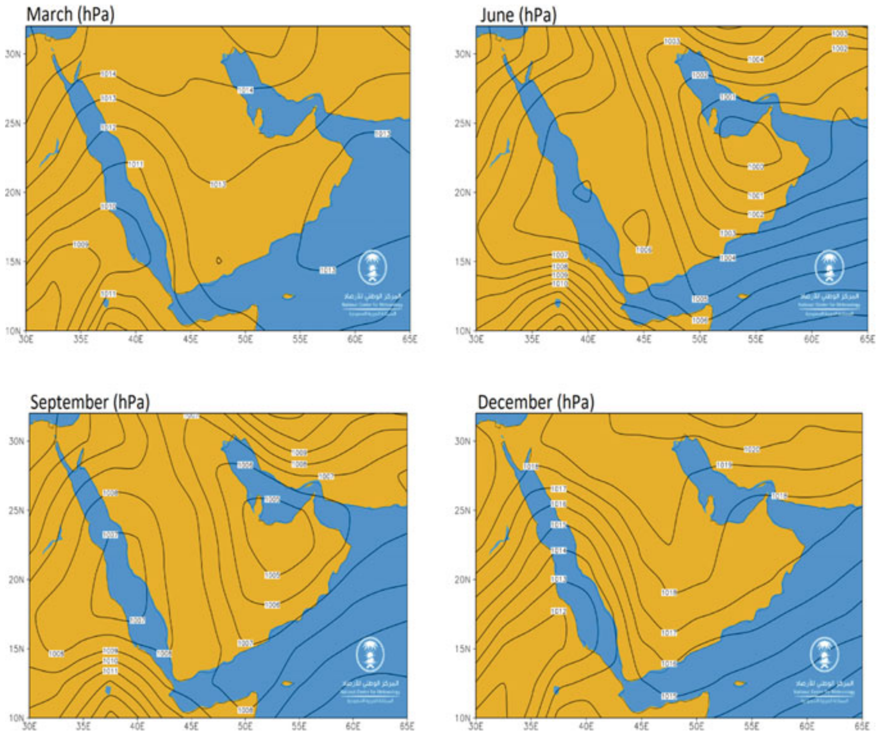



**Fig. 8** The patterns of pressure averages at sea level in the KSA for the period from 1985 to 2019

Decree no. 22/M dated 12/9/1406AH/1986. The NCWCD is now known as the National Center for Wildlife, NCW). The main objectives of this commission are to develop and implement plans defining the risks to terrestrial and marine wildlife, to rehabilitate extinct and endangered species, and to restore the ecological balance of the national natural ecosystems (NCW 2022a, b). Since then, the Saudi Wildlife Authorities have achieved thriving successes in securing and stimulating the biological varieties in the country. Nevertheless, they still face various challenging issues to sustain these achievements and goals (Alatawi 2022). They have allocated 16 national protected areas covering 86,582.4 sq km and planned another 22 areas covering 208,356 sq km, to ultimately totaling 294,938 sq km about 13.72% of the KSA total area (Barichievy et al. 2018). Figure 13 shows the distributions of the prime protected areas in the country (Al-Tokhais and Thapa 2019).

Lastly, it is worthy to signify that almost 50% of the land in the KSA is viable for cultivation (arable), with only part of it has a limited suitable irrigation water (Karrar et al. 1991). It is therefore possible to suggest that such natural resources need to be properly invested for agricultural activities and hence improved food productions in the country, as the national food security is conceivably accomplished.

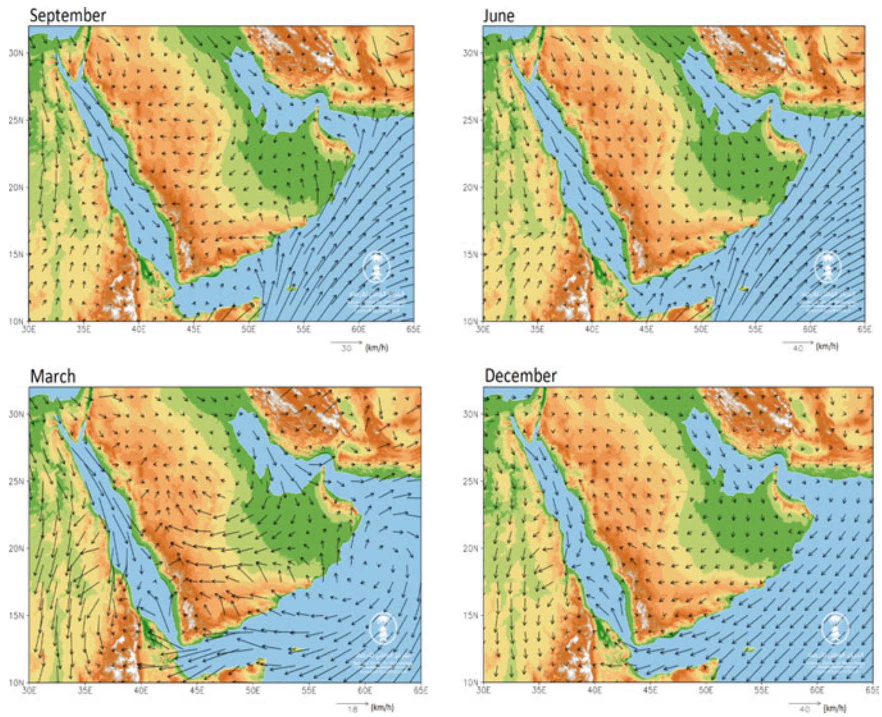



**Fig. 9** The patterns of wind directions in the KSA for the period from 1985 to 2019

### 2.5.2 Soil Resources

More than one third of the KSA land surface area is covered by sandy deserts consisting of shifting sand dunes (Ashraf 1991; Karrar et al. 1991; MAW 1985). The soils of these dunes are classified as Torripsainnients/Calcaric Arenosols. These soils are intensively found in the deserts of Al-Rub Al-Khali, Al-Nafud, and Al-Dahna, with some small-isolated areas being found elsewhere. Likewise, there are narrow strips of sandy soils along the coastal areas of the eastern and western regions, where the soils are classified as Udipsaminents/Gleyic Arenosols. These soils are recognized mainly by their high water-table as they are affected by the tidal sweeps (Ashraf 1991; Karrar et al. 1991) that trigger them to be continuously wet. Also, it was revealed that there are bulk of soils all over KSA of a loamy texture and shallow to deep profile over bedrock horizon (Torriorthents) that occur on gentle to steep slopes exposing them to a dynamic erosion process (Karrar et al. 1991; MAW 1985).

Furthermore, most soils in the KSA are considered young (immature), as they lack much pedogenic development due to moisture scarcity and continuous renewal of their surfaces by erosion and deposition processes. However, in small areas scattered over the country, there are soils with genetic horizons that are considered as relatively old (MAW 1985, 1995). Also, most KSA soils are calcareous, being classified as

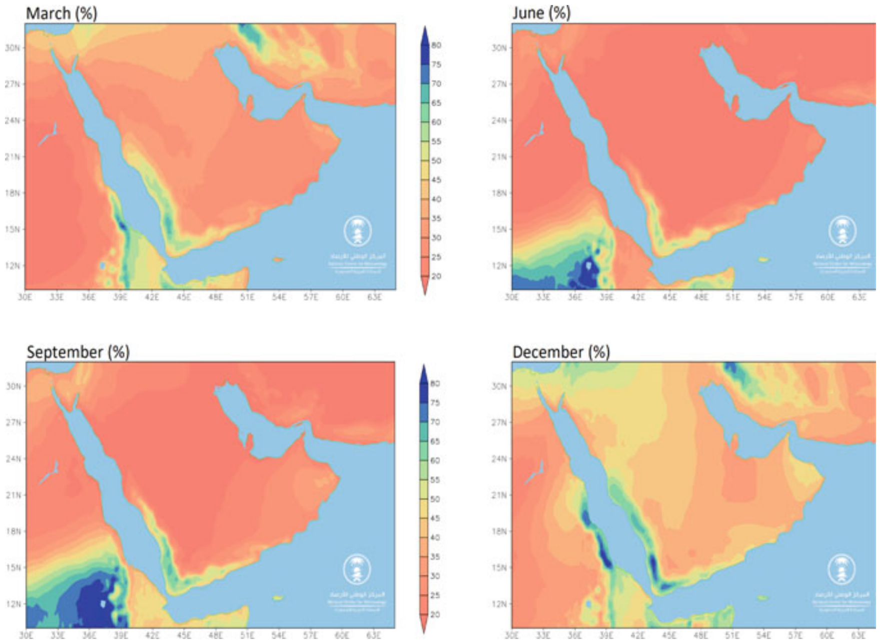



**Fig. 10** The patterns of humidity in the KSA for the period from 1985 to 2019

Calciorthids / haplic Calcisols with carbonate contents ranging from 10 to 15% in sandy soils and 15–40% in loamy soils. This is due to the lack of rainfall to leach out the carbonates and other salts (Al-Barrak and Al-Badawi 1988; Ashraf 1991; Karrar et al. 1991; Shadfan et al. 1984). The main soil orders in the Kingdom are Entisols, Inceptisols, and Aridisols (MAW 1985, 1995).

In the KSA, the prevailing properties of the cultivated soils are coarse texture, low organic matter contents ($\leq$ 1%), poor soil fertility (deficit in available nitrogen (N) and phosphorus (P), moderate availability of potassium (K), and insufficient of micronutrient contents), and high salinity levels (Alghamdi and Hegazy 2013; Al-Ghamdi et al. 2021; Alharbi et al. 2017; Ehlen and Henley 1991; Falatah and Al-Darby 1993; Majjami et al. 2020a, b). Elevated salinity in the cultivated soils of the KSA forms a major constraint impeding the agricultural activities and hence food productions (Al-Barrak and Al-Badawi 1988; Alharbi et al. 2017; Almadini et al. 2007, 2012; Elhag 2016; Majjami et al. 2020a, b; Modaihsh et al. 2014; Shadfan et al. 1984).

About 40% of the KSA soils are impacted by salinity with a varying range from non-saline to strongly saline according to Karrar et al. (1991), who also added that there are many closed basins (sabkhas) that have inadequate drainage capability, yet they receive runoff water from adjacent areas causing water-table to rise and ultimately the soils to be severely saline (Saborthids) with formed salt crusts at the soil surface. These soils are mostly in the northern and eastern regions of the

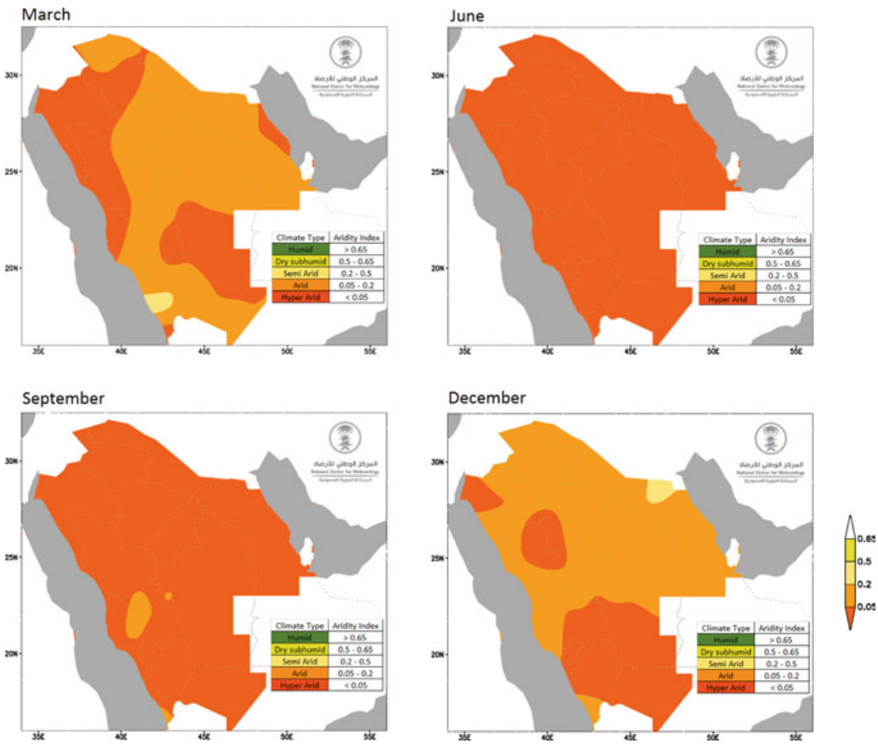



**Fig. 11** The patterns of climate classification in the KSA for the period from 1985 to 2019

country. The sabkhas in KSA are widespread along the coastal lands of the Red Sea and the Arabian Gulf (coastal sabkha) and in several locations inside the country (inland sabkha) (Al-Mhaidib 2002; Alotaibi et al. 2020; Sabtan and Shehata 2022). However, the sabkha ecosystems are useful natural sources for various minerals (Na K and Mg) and renewable fresh water (Sabtan and Shehata 2022; Saeed et al. 2020).

Such soil properties generate hindering factors for agricultural developments and so the food productions. Thus, it is trustworthy to insinuate the real needs to implement good agricultural practices including modern farming technologies to overcome such constraints with an aim to strategically attain food security and sustainability of other natural resources in the country.

### 2.5.3 Water Resources

The KSA is a massive country characterized by its scanty water status, as it lacks permanent surface fresh-water bodies, as lakes or rivers (Al-Ibrahim 1990, 1991; Baig et al. 2020; Chowdhury and Al-Zahrani 2015; MAW 1984). Globally, it is considered one of the 26 countries that suffer from water scarcity, the annual water availability

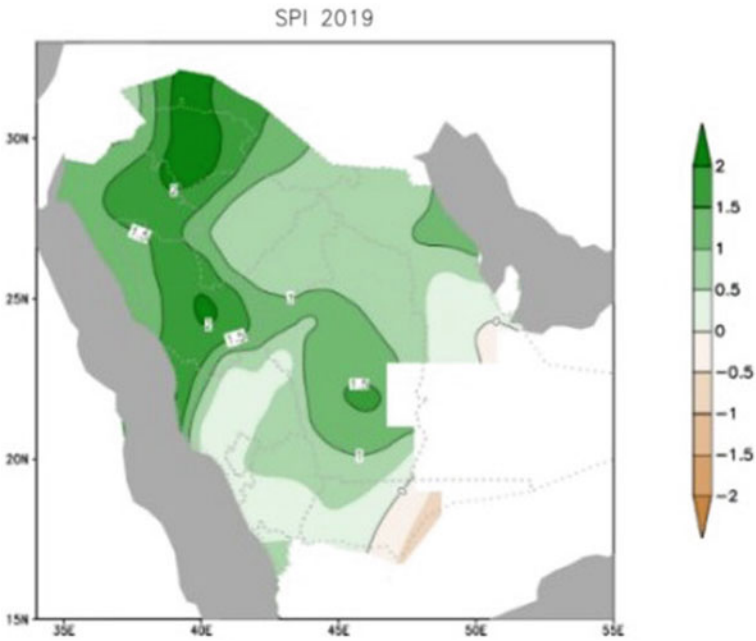



**Fig. 12** The patterns of SPI index in the KSA for the period from 1985 to 2019

**Table 1** The SPI index key values

| Class | SPI value | Class | SPI value |
|---|---|---|---|
| Extreme wetness | ≥ + 2.00 | Low dryness | − 0.0 to − 0.99 |
| Severe wetness | + 1.50 to + 1.99 | Moderate dryness | − 1.00 to − 1.49 |
| Moderate wetness | + 1.00 to + 1.49 | Sever dryness | − 1.50 to − 1.99 |
| Low wetness | + 0.00 to + 0.99 | Extreme dryness | ≤ -2.00 |

*Source* NCM (2022)

per person is < 1000 $m^3$ (Pimentel et al. 1997). Also, it is the third highest country worldwide consuming fresh water per capita (Baig et al. 2020), with a value about 270 l/person/day (~ 99 $m^3$/person/year) in 2016 (GCC-STAT 2016). This means that the available water resources in the country are in a meager condition to meet water requirements for the developments of the agricultural, industrial, and environmental sectors.

The water requirements in the KSA are supplied from three major resources, namely: underground water, desalinated water, and treated wastewater (Baig et al. 2020; Chowdhury and Al-Zahrani 2015; MAW 1984). The underground water resource includes both non-renewable water (deep underground/fossil) and renewable water (surface or shallow underground). The non-renewable underground water comes from eight principal and several secondary aquifers being differentiated on

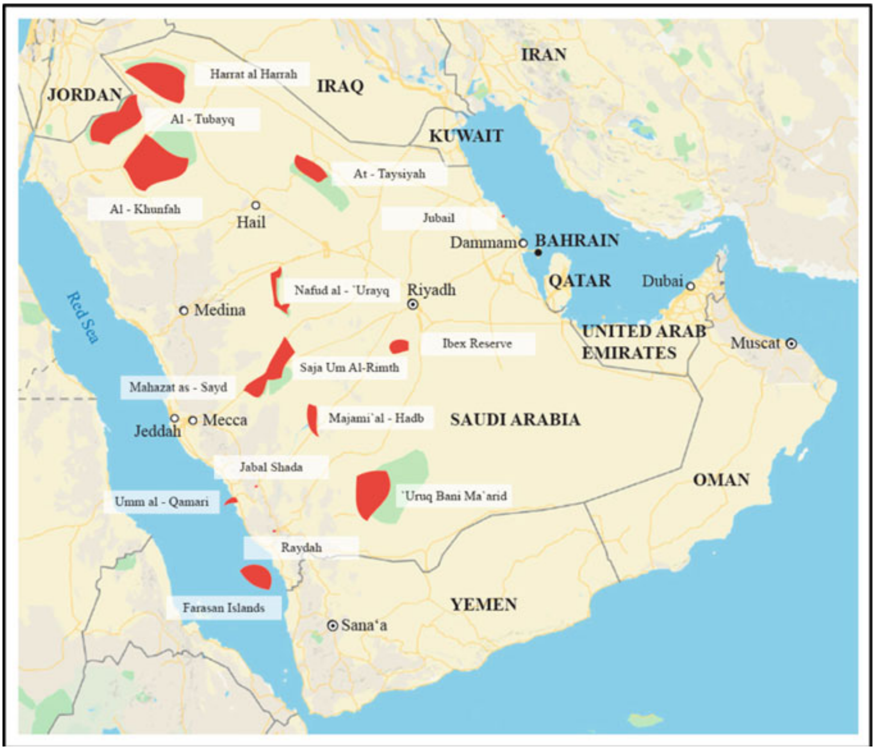



**Fig. 13** The distributions of prime protected areas in the KSA (Al-Tokhais and Thapa 2019)

basis of their hydrological properties and spatial extent (Al-Ibrahim 1990, 1991; Chowdhury and Al-Zahrani 2015; MAW 1984). The principal aquifers are formed of sedimentary deep rock (sandstone and limestone) and have greater permeability and larger yields than the secondary aquifers. The principal aquifers are about 300–500 m thick and 120–2000 m deep, with their water reservoirs being formed during the Ice Era (about 10,000–32,000 years ago). Al-Ibrahim (1991) suggested that principal aquifers retain about two third of the non-renewable underground water. The estimates of their water reserves however have been reported by several studies proposing different outcomes (Chowdhury and Al-Zahrani 2015), which signifies the real needs for recent studies comprehensively investigating their geohydrological traits. Figure 14 displays the distributions of these aquifers of non-renewable underground water in the KSA (Al Zawad 2008).

Meanwhile, the renewable water resource consists of shallow underground water and surface water that includes runoff water in wadis (valleys) during rainy seasons and water reserved behind the constructed dams (Mallick et al. 2021; Baig et al. 2020; Chowdhury and Al-Zahrani 2015; MAW 1984). The underground renewable water is mainly found in the shallow alluvial aquifers and within Basalts that largely extend in the southwestern regions of the Kingdom. These aquifers are characterized

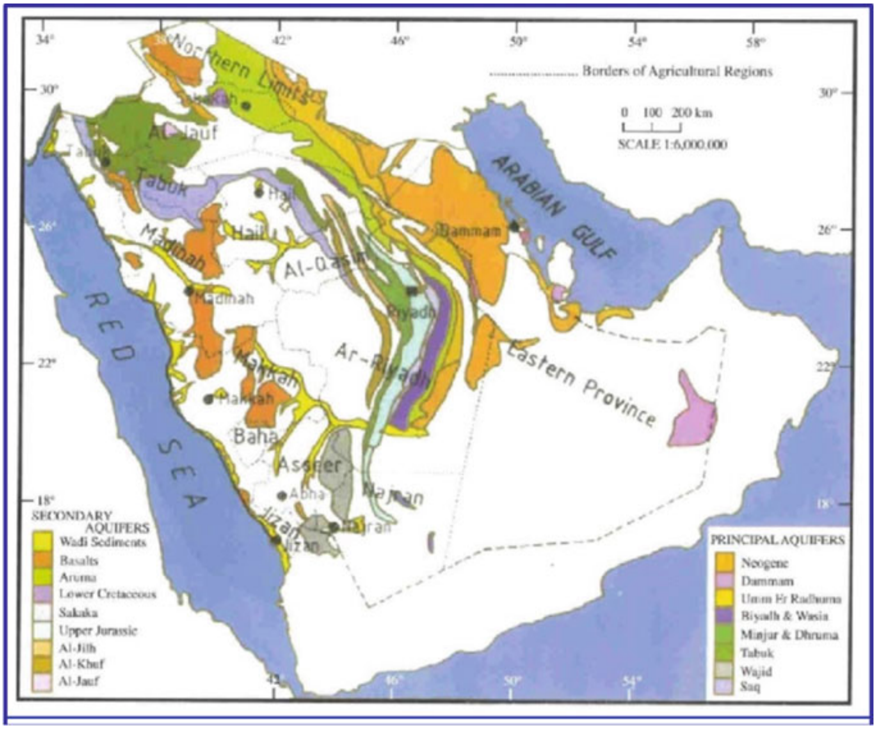



**Fig. 14** The distribution of principle and secondary aquifers of the non-renewable underground water in the KSA (Al Zawad 2008)

by their variable thickness and depth. Despite of the meager rainfall throughout most parts of the KSA, the average of estimated annual recharge taking place into these aquifers is about 1.2 million m$^3$. 60% of surface runoff water occurs in the Tihama (southwest) region that cover only 2% of the total KSA area. This region receives the highest quantity of rainfall in the country (up to 600 mm/year, please see Sect. 2.4), making it the most crucial region in terms of surface water resource. The estimation of the annual surface water runoff in the KSA is $\geq$ 2 billion m$^3$, with major part of it is being stored behind the dams (Chowdhury and Al-Zahrani 2015; Obai 2015; MAW 1984).

According to the 2020 statistical book prepared by the Ministry of Environment, Water, and Agriculture (MEWA 2020a), there are 532 dams in the Kingdom, with a total storage capacity of 2335 Million m$^3$, as compared to 507 dams with a storage capacity of 2,265,789,655 m$^3$ in 2017. Most of these dams are in the southwestern provinces [Asir (117 dams), Al-Baha (51 dams), Jizan (15 dams), and Najran (26 dams)] of the country, with a total storage capacity of 1,068,724,803 m$^3$ (~ 46% of the total storage in the KSA). Obai (2015) indicated that the main purposes for constructing these dams in the KSA are to recharge water into shallow aquifers, to control floods protecting cities and villages, and to provide potable water for the neighboring cities and villages after being properly purified, and to provide irrigation water for farms in surrounding areas. The 2015 statistical report by the Ministry of Water and Electricity (now is a part of MEWA) indicated that there are 21 purifying plants with a total production capacity of 714,000 $m^3$/day in the country (MWE 2015). These plants are built on the dams in Asir (10), Makkah Al-Mukaramah (5), Al-Baha (3), and Jizan (3).

The KSA is globally the leading country producing fresh water by desalinating seawater, with about 30% of the World's production capacity (Drewes et al. 2012; Ghanim 2019; MWE 2015; Sewilam and Nasr 2015). In 2015, the desalinating seawater plants in the Kingdom were 27 plants (18 principals and 9 smalls), being distributed along the coasts of Red Sea and Arabian Gulf. They produce $\geq$ 1.2 billion $m^3$/year averaging 77% of their full production capacities. This reduction in their outputs however is due to the regular maintenance and development requirements as well as to the sudden or intended shutoffs. In addition, there are numerous private plants that also contribute to the national desalinated water productions. These plants produced in 2015 an amount of fresh water equals to 576.8 million $m^3$ (MWE 2015). However, in the year of 2020, the produced amount of desalinated fresh water was ~ 2.28 billion $m^3$, covering ~ 62.70% of the total municipal water demands (~ 3.63 billion $m^3$). The rest of these demands comes from the underground water (~ 33.71%), surface water (~ 3.35%), and other resources (~ 0.24%) (MEWA 2020a). Statistically, the production of desalinated water has shown an increase of 69.87% between 2010 (1258 million $m^3$/year) and 2018 (2137 million $m^3$/year) (GASTAT 2018a), which reflects the national interests to benefit from such unconventional water resource.

The KSA authorities have also promoted great attentions to benefit from the sewage water after being properly treated as a renewable water resource to lessen the rising stresses on fresh water from underground resources used in agricultural, commercial, and industrial sectors (Drewes et al. 2012; Ghanim 2019; Ouda 2015; Qureshi 2020). In 2020, there were 116 sewage treatment plants in the country, producing daily ~ 5.11 million $m^3$ (~ 1.87 billion $m^3$/ year) (MEWA 2020a). Off this amount of treated sewage water, only 929,252 $m^3$/day (~ 0.34 billion $m^3$/year) has been reutilized equaling about 18.20% (MEWA 2020a). However, this amount of produced treated sewage water in 2020 has increased 27.21% (~ 5.54% a year) as compared with the total amount produced in 2015 (1.47 billion $m^3$) (MWE 2015). In fact, the amount of treated sewage water in KSA has displayed an increasing trend since 2010, achieving 60.08% between 2010 (1.02 billion $m^3$) and 2018 (1.67 billion $m^3$) (GASTAT 2018b).

However, reutilizing such treated sewage water in the country faces great challenges, as low social acceptance, high cost of needed infrastructure (constructing treatment plants and water transporting networks), distances between produced and benefited areas, and probable health risks (Ghanim 2019; Ouda 2015; Qureshi 2020). Despite of these barriers, Ouda (2015) stated that the Saudi government planned to fully reuse produced sewage water in the country by 2025 after being properly treated, particularly in villages and cites having a papulation of 5000 or more. This reflects the sincere interests by the responsible authorities in the country to benefit from this renewable water resource, taking into considerations the steadily growing population in the Kingdom.

Briefly, the previous discussions regarding these existing national related agricultural resources (the natural resources, soils, and water) in the Kingdom have considerably introduced the apparent potentials of the country to produce an immense part of its food requirements that will contribute to the achievements of the national food security advocated by the authorities. Nevertheless, it is conceivable to insinuate that there are undisputable needs to employ good and scientific farming practices to develop and sustainably utilize these vital national resources.

## 3 KSA Agricultural Sector

### *3.1 Agricultural Sector Initiation and Development*

The Saudi agricultural sector has been historically receiving enormous attentions and supports by the consecutive Saudi governments since the time of His Highness King Abdulaziz, may Allah Almighty has mercy on his soul, the founder of KSA. In 1932, the Shura Council made a decision that was ratified by HH King Abdulaziz to exempt agricultural imported commodities from customs' duties and commence an agricultural development movement by allowing the Ministry of Finance (MoF) to import some agricultural machineries and supplies to be distributed among the local farmers at affordable prices (MEWA 2022). Since then, the sector has been gaining further praises and formality, reflecting the authorities' recognitions to its national importance.

The agricultural sector in the KSA had its first formal scheme as a General Directorate of Agriculture in 1947 under the Ministry of Finance (MoF). Then in 1953, it became an independent ministry under the title of the Ministry of Agricultural and Water (MAW) according to the Royal Decree no. (5/21/1/4951) dated on 24/12/1953. After the 1953, the sector has undergone through serious revisions in its tasks and names, till issuing the Royal Decree no. (A/133) dated on 7/5/2016 that had amended its name to be the Ministry of Environment, Water, and Agriculture (MEWA) and its principal obligations and objectives (MEWA 2022). The Decree has also specifically defined the MEWA's primary objectives, among which are the followings:

(a) Managing and developing the KSA environmental, water, and agricultural subsectors.
(b) Planning and implementing the national strategies of environment, water, agriculture, and food security.
(c) Granting flexible profit-free loans for farmers via the Agricultural Development Fund (ADF).
(d) Organizing the distributions of lands for cultivation and agricultural projects.
(e) Conserving the KSA natural resources and protected areas and combating desertification.

(f) Promoting the adoptions of modern practices and technologies in the KSA agricultural, livestock, and fisheries subdivisions and their related industries.
(g) Motivating water harvest in the country by planning, managing, and constructing dams as well as irrigation and drainage projects to promote water use efficiency.
(h) Improving the productive potentials of local foods seeking the attainments of the national food security.
(i) Planning quarantine systems in the Saudi's customs at borders, airports, and seaports to protect the national agricultural and animal resources.
(j) Developing national aquatic resources as a source of foods contributing to food security.
(k) Protecting of the national fish territories and aquatic environment.
(l) Conducting field studies to adopt modern and scientific technologies in environment, water, and agriculture (farming, livestock, and fisheries) in the country.
(m) Fostering the internal and external national agricultural marketing and investments.

## *3.2 Establishment of Agricultural Development Fund*

One of the Saudi Arabian governmental strategic movements to support the agricultural sector in the country is setting up a financial firm that provides flexible profit-free loans to the sector's numerous activities. This was attained by establishing the Saudi Arabian Agricultural Bank (SAAB) under the Royal Decree no. (58) dated on 3/12/1382 H (1962), with a particular aim to finance the various agricultural activities promoting the national agricultural sector and enhancing the applications of best modern and scientific technologies to augment the sector's productivity potentials and contributions. The SAAB was then upgraded in 29/1/1430 H (2010) to be the Agricultural Development Fund (ADF) as a national crediting firm. Such conversion has come to the light after the Saudi's Council of Ministers approved the proposal of the Council of Shura under the Decision no. (71/106) dated on 2/4/1429 H (2010) that also specified the ADF bylaws and protocols as well as assigned its initial budget at a value of SAR 20 billion. This budget however can be increased by the approval of the Council of Ministers (ADF 2022). The ADF offers four types of profit-free loans that are of short or long terms. These types of loans are as followings:

(a) Development loans: These loans are those directly offered on basis of long terms to develop farms that cultivate crops and fruits, farms raising bees, fishery boats, agricultural tourism, veterinary clinics and pharmacies, and vegetable transporting trucks.
(b) Specialized projects' loans: These projects are those investing economic resources to build and manage productive systems to obtain an annual return in a designated period. Such loans are of long terms, being directly offered to specialized projects whether new, upgraded, or restructured. The loans will be

decided based on economical assessment study and a license from the MEWA. The return payments of these loans are determined based on the project's cash flows, assessment study, and credited analysis.

(c) Normal operating loans: These are to cover the operating costs of a single productive cycle of small facilities. These loans are directly offered on basis of short terms and must be paid back in one year only.
(d) Operating loans for specialized projects: These loans are one of the important services offered by the ADF providing an opportunity to receive direct loans to finance an active capital. These loans are of short terms that cover the operating costs of a single productive cycle. They are offered to specialized activities with their back payments should not exceed two years.

The key aims of the ADF are to protect the national water and environment resources; support the agricultural development and its sustainability with flexible profit-free loans and necessary crediting facilities; and financing the agricultural sector achieving food security and natural resources sustainability (ADF 2022). The ADF however has been assigned with general objectives that include the followings:

(a) Financing the subsectors' activities intending to achieve the national food security and natural resources sustainability.
(b) Providing finance to local farmers to employ sustainable farming and rural development considering the variations in relative incentives between the provinces.
(c) Supporting the utilization efficiencies of national resources and advocating employments of modern technologies.
(d) Funding the cooperative societies and projects supplying products and support services.
(e) Employing effective finance and human resources as well as systems of information technology.
(f) Achieving the dependency of sustainable finance, growth of finance capital, development of governance system, and management of comprehensive risks.

Since its formation, the ADF has noticeably assisted the sustainability of agricultural sector by funding more than 460,000 beneficiaries with profit-free loans totaling > SAR 51 billion (about US$ 13.6 billion), covering various agricultural activities (Fig. 15) (MEWA 2020b). These substantial funds have commanded the country to remarkable achievements that will be outlined in detail in next section.

### *3.3 Agricultural Sector Achievements*

As a results of the generous governmental supports, the Saudi agricultural sector has achieved remarkable successes. In 2019, it had contributed a value about SAR 53 billion ( more than US$ 14 billion) to the gross domestic product (GDP), equaling to ~ 3.4% of the non-oil GDP (MEWA 2019a). This percentage in fact is a distinctive

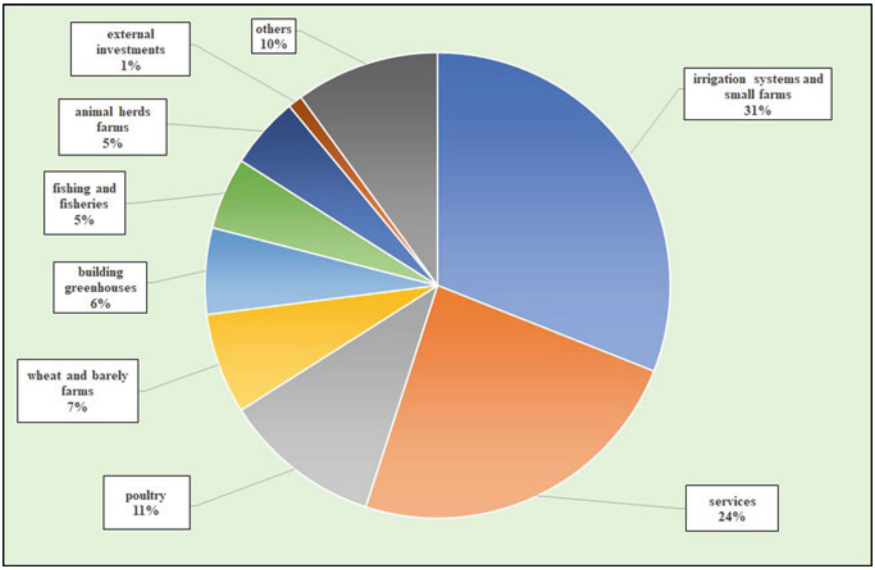



**Fig. 15** The various funded agricultural activities and the percentages of their received funds from the ADF (MEWA 2020b)

value from the perspectives of the non-oil source contributions in the country. It had also vital inputs to the national economics, as it has involved 910,000 employees who worked in the established 346,567 farms that included 262,000 farms of the farming activities (75.60%) and 84,567 farms of the husbandry's and fisheries' activities (24.40%) (MEWA 2019a).

In 2018, the cultivated areas in the KSA included 1,123,991.04 ha for grains (wheat, barley, Rhodes, maize, corn, millet, sorghum, sesame, coffee, and others), 2,043,775.86 ha for fodders (alfalfa, clover, barley, Rhodes, blue-panic, and others), and 348,624.36 ha for open field vegetables (tomato, squash, cucumber, watermelon, lettuce, aubergine, green pepper, potato, onion, okra, mint, leek, radish, cabbage, cauliflower, carrot, and others). These open field vegetables were winter (56.28%) and summer (43.62%) crops. These cultivated open areas produced 1,440,065 tons of grains, 9,132,687 tons of fodders, and 1,748,392 tons of open vegetables (54.00% winter and 46.00% summer) (MEWA 2019a).

Furthermore, there were also in 2018 other agricultural crops produced under the greenhouses, including various vegetables (tomato, squash, cucumber, aubergine, green pepper, lettuce, melon, parsley, broccoli, Jew's mallow, coriander, artemisia, spinach, leek, mint, and others) and cut-flowers (Taif roses, jasmine, basil, domestic roses, pink, rosa damascene, palm kernel, Madinah roses, daffodils, lilies chrysanthemums, sage, rosa canina, musk bugle, and others). The total number of the greenhouses reached to 73,542 for vegetable productions and 4919 greenhouses for cut-flowers productions. The total areas of these greenhouses were 32,947,306 $m^2$ and 2,410,106 $m^2$, respectively (MEWA 2019a).

Also, fruitful trees of date palm and evergreen have been given considerable interests. In 2018, the date palm trees in the country reached to an unprecedented total number of 31,234,155 trees, producing 1,539,755 tons of fresh dates. More than 75% of these trees were found in four provinces, which are Riyadh (7,924,947 trees, 25%), Qassim (7,542,914 trees, 24%), Madinah (4,751,040 trees, 15%), and the Eastern (4,000,000 trees, 13%). The Khalas cultivar was the most planted one in the country with 7,903,510 trees (25.30%), followed by the Yellow Sukkari (15%), Barni and Sufri (7% each) (MEWA 2019a). The National Center for Palms and Dates (NCPA) reported in 2020 that the Saudi productions of dates reached to 17% of the World's total production of dates, resulting in a surplus in the country's needs (125% of self-sufficiency) and boosting its export of dates to 73% in value and 68% in quantity as compared to the 2015 productions, with an annual average increase of 12% in quantity. These exported quantities reached to 107 countries (NCPA 2020). These successes were escorted by 42 specialized factories registered in the Saudi Dates Trademark that produced 432,720 tons in the same year (NCPA 2020).

There were also 28,000,000 evergreen trees in the country in 2018. More than 70% of these trees (20 million trees) were fruitful that included 14,308,912 olive trees (65% fruitful), 5,014,178 grape trees (89% fruitful), 1,282,705 lemon trees (84% fruitful), 1,170,198 mango trees (87% fruitful), 1,104,784 pomegranate trees (81% fruitful), and 8,234,272 other evergreen trees (72% fruitful). Both of Al-Jouf and Tabuk provinces had most of these evergreen trees with 46% and 17% of total number of the KSA evergreen trees, respectively (GASTAT 2019a).

As a vital part of the agricultural sector, the animal resources in the KSA had similarly gained noticeable successes. In 2015, the statistical data of the total number of animals held in the non-specialized farms (non-projects, houses, and others) comprised of 9,055,438 sheep, 3,563,017 goats, 471,276 camels, and 354,276 cows, that were raised in 64,396, 48,881, 13,760, and 7338 farms, respectively (GASTAT2015). Likewise, there were a variety of birds grown in specific holdings (non-specialized farms). These included 1,872,955 chickens (20,376 holdings), 2,980,315 pigeons (13,221 holdings), 129,313 ducks (3329 holdings), 12,550 turkeys (440 holdings), 24,539 geese (990 holdings), 433,695 quails (219 holdings), 154,390 rabbits (2925 holdings), 1676 ostriches (137 holdings), 1312 peacocks (119 holdings), and 7375 others (4 holdings) (GASTAT 2015).

Moreover, there were other animals that were raised in specialized farms (project farms). The details of their data are summarized in Table 2, which includes the number of the farms and their barns' number and total areas ($m^2$) as well as their total capacities in total number of birds (GASTAT 2015). Thus, a total of 351 projects of broiler specialized farms were added in the year of 2018, with 3564 barns of a total area 12,312,860 $m^2$ and a capacity of 139,556,643 poultries (GASTAT 2019b). These broilers specialized farms have also used 829,355,978 chicks and produced 1,137,340 tons. These farms also produced 3074 ton of meats from rabbits, ostrich, quails, and pigeons, with ostrich's meat being the highest at 2565 tons (~ 83%) (GASTAT 2019b). In the same year, the ostrich, quails, and pigeons also produced ~ 39 million eggs, with 38 million eggs from quails (~ 97%). Moreover, the ostrich produced 4 tons of leathers (43%) and feathers (57%) (GASTAT 2019b).

**Table 2** Data summary of total number of animal specialized farms in the KSA and their barns' number and total areas as well as their total capacity in 2018

| Animal types | Number of farms | barns | | Total capacity (birds) |
|---|---|---|---|---|
| | | Number | Total area ($m^2$) | |
| Cows | 138 | 5820 | 19,486,557 | 438,819 |
| Broilers | 351 | 4684 | 9,292,131 | 181,564,167 |
| Broiler mothers | 43 | 980 | 1,603,964 | 9,127,333 |
| Broiler grandmothers | 6 | 45 | 99,368 | 301,160 |
| Layer chickens | 129 | 3271 | 3,550,702 | 27,935,169 |
| Layer chicken mothers | 20 | 141 | 307,954 | 801,040 |
| Layer chicken grandmothers | 6 | 45 | 170,900 | 220,800 |
| Quails | 3 | 123 | 61,884 | 2,772,000 |
| Ostriches | 2 | 231 | 63,050 | 948 |
| Rabbits | 3 | 13 | 344 | 308 |
| Total | 701 | 15,353 | 34,636,854 | 223,161,744 |

*Source* GASTAT (2019c)

Furthermore, the 2018 statistical survey in the KSA indicated that there were 13 cattle specialized farms of three types, namely: dairy (5 farms, 39.4%), calf fattening (3 farms, 21.2%), and dairy calf fattening (5 farms, 39.4%) (GASTAT 2019c). These farms consist of 1406 barns with an area exceeding 8,000,000 $m^2$. The total number of cows in the country were 400,561 cows, of which about 50% were under 2 years old (200,873 cows) and the rest were 2 years old or more. There were 58,973 male cows (14.72%), most in Riyadh province (65.77%). However, the milking females were 195,346 cows in the specialized farms, produced 2,393,771,000 l of milk. In addition, these cattle specialized farms produced 142,241 tons of dairy products, 90% of which was produced in the Eastern province, followed by the Riyadh province with 7% of total productions. These cattle farms though had used 349,824 tons of green fodders, 63,937 tons of synthesized fodders, 714,573 tons of dry fodders (GASTAT 2019c).

There were also specialized farms for layer chickens and hatcheries. In 2017, the total number of these farms was 175 farms that had 2293 barns with a total area of 6,748,221 $m^2$ and a capacity of 45,542,408 birds (GASTAT 2018c). In the same year, these farms produced 6,260,174,115 eggs, among which were 5,256,373,907 table eggs (83.97%) and 1,003,800,208 hatching eggs (16.03%). Also in the same year, survey data indicated that there were a total number of 12 specialized hatcheries of which 9 specialized for broilers (75%) and 3 specialized for layer chickens (25%). These two types of specialized hatcheries used 224,169,150 and 27,790,000 eggs, respectively (GASTAT 2018c).

The activities of fishes and fisheries in the country have received substantial supports benefitting from the long coastal distances on both Eastern and Western borders, as indicated earlier. There are a variety of fishes being produced in the country, which were grown in specialized farms containing ponds of concrete (44.50%), earth (36.70%), fiberglass (11.10%)), and other (7.60%) types (GASTAT 2019d). In 2015, the total number of fish farms were 109 containing 3256 ponds with a total volume 14,598,810 $m^3$ (GASTAT 2015). Table 3 outlines the summary of the fish types, the number of fish farms and the ponds used in numbers as well as in volumes. In 2018, the total fish production was 86,662 tons of which 67,160 tons was prawns (77.50%) (GASTAT 2019d). The total number of juvenile fish used in these fish farms was more than 180 million fish.

In the Kingdom, there were also some activities concerning the beehives and their honey productions, taking advantages of the flower nectars provided by the cultivated farms and the natural resources for their needs. In 2015, there were 38,878 beehives producing 109,480 kg, among these were 26,212 traditional hives producing 61,883 kg (56.46%) and 47,597 modern hives producing 38,878 kg (43.46%) (GASTAT 2015). It is worth to indicate that growing beehives in the country

**Table 3** Summary of the fish types, the number of fish farms and their ponds in numbers and volumes in the KSA during 2015

| Fish types | Number of farms | Ponds | |
|---|---|---|---|
| | | Number | Volume ($m^3$) |
| Fishes: | | | |
| Arabian | 48 | 80 | 65,436 |
| Indigo tilapia | 18 | 2165 | 942,148 |
| Marine tilapia | 15 | 362 | 24,868 |
| The sturgeon | 2 | 160 | 14,400 |
| Subaiti | 2 | 2 | 61 |
| Asian Seabass | 2 | 13 | 29,200 |
| Grouper | 4 | 16 | 17,724 |
| European Seabream | 3 | 12 | 223,237 |
| Shrimps (Prawns): | | | |
| Qazzazi shrimps | 1 | 64 | 4,480,000 |
| Indian shrimps | 1 | 178 | 10,000 |
| Vanami shrimps | 2 | 106 | 5,991,600 |
| Algae: | | | |
| Ketoseros algae | 4 | 4 | 67 |
| Thalesusra algae | 4 | 4 | 21 |
| Others | 3 | 90 | 2,800,048 |
| Total | 109 | 3256 | 14,598,810 |

*Source* GASTAT (2019d)

is a well-established traditional activity, particularly in the southwestern and western regions as they are relatively rich with the rangelands and forests, as specified earlier. However, this industry nowadays receives marked supports to adopt modern practices involving scientific techniques that caused its widespread over the country. As part of its 2018 rural development program, the ADF for example has funded a specialized beehive project with SAR 1,858,012 to produce 10 tons/year of honey (ADF 2018). This finance loan is one of the top funds by the ADF in that year for a specialized project.

Briefly, these agricultural achievements have advanced the KSA to successfully produce major portions of its food requirements. Indeed, these achievements are vital components of the country's efforts to achieve its targeted food security in compliant with the main objectives of the ambitious national 2030 strategic vision. However, it is worthwhile to affirm that the local food productions in a desert country like KSA are expected to be short to meet its full domestic needs, which mandates circumstances to import its lacked food commodities from other countries.

## 4 KSA Food Security: Ambitions and Impediments

### *4.1 Food Security Basic Principals*

Plenty of people simply assume food security as a case when enough foods are available at any time. However, the Food Security World Summit organized by the FAO in Rome, Italy during the period of 13–17 November 1996 specifically declared 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 definition of food security though has undergone various revisions since the nineteenth century till its first-time introduction in 1974 and thereafter to gain its prescribed form in the 1996 World Summit when it was refined with specific dimensions that had granted its wide acceptance by international organizations, policy makers, and academics (Barrett 2010; Clapp 2015; Clapp et al. 2022; FAO 1992, 2006; Engler-Stringer 2014). These long-lasting revisions of the food security definition signify the variations in the official thinking of authorized agencies and specialists as well as comply with concerns regarding the famine and its impacts on human life (Fernández-Wulff 2013).

Clapp (2015) indicated that the food security definition had evolved through six crucial stages with the first one was between the 19th and early twentieth centuries when concerns of countries were on food self-sufficiency as part of their national security, the second stage was in middle of twentieth century when growing attentions were devoted to the universal impacts of famine, the third stage was in 1970s when the term of food security was first introduced and gained global prospects, the fourth stage was in 1980s when the focus of food security was shifting from production to integrate access and to involve individuals, the fifth stage was in 1990s when growing interests were toward the nutrition dimensions of food security as well as the rise of food sovereignty concept, the sixth stage was in 2000s when the four dimensions (pillars) of food security (availability, accessibility, stability, and utilization) were established and interests were motivated towards the right to the food, the food sovereignty, and the new dimensions of nutrition. This shows that the concept of food security is always under revisions seeking its progress and global acceptance. These aforesaid four dimensions of food security however were recently upgraded with both agency and sustainability to become six dimensions (Clapp et al. 2022).

In their review of published literatures and reports by academics and global organizations dealing with food security and its dimensions, Clapp et al. (2022) proposed that agency dimension denotes the ability of individuals and groups to perform self-control over their surroundings and the elaboration of sincere efforts into governance activities aiming to overcome the spreading inequities in food systems; whilst, sustainability dimension deals with food system practices that promote the long-term renovation of natural, social, and economic schemes to balance between the food needs for present generations with those for future generations. Moreover, the authors concluded that compiled knowledge and interpretations of these published materials have corroborated the insights of food security dimensions to be more precise with time, suggesting that both agency and sustainability are decisive components of the food security's dimensions due to the cumulative evidence in context of the increasing food system inequities and the growing perceptions of sustainability implications of current food systems.

Several studies have disclosed that agricultural productivity and productions are prime factors in feeding the World's growing population and ensuring food security (Angelo 2017; Fakhri 2020; Pretty et al. 1996; Smutka et al. 2009). The main concerns of authorized global organizations and international governments are to provide enough foods to the growing world's populations and to diminish the starvation of almost a billion people in the World. The Population Division at the Department of Economic and Social Affairs of the United Nations indicated that the World's population in 2019 was 7.7 billion, being projected to grow to nearly 8.5 billion in 2030, 9.7 billion in 2050, and 10.9 billion in 2100 (UN 2019), suggesting that such rapid population growth would present a challenging aspect to the Sustainability Development Goals. Among these goals are to "end poverty in all its forms everywhere" and "end hunger, achieve food security and improved nutrition, and promote sustainable agriculture" (UN 2021).

### *4.2 KSA Food Security Ambitions*

According to the insights of the development of food security concept and its dimensions previously mentioned in Sect. 4.1, the Saudi government has strategically considered food security as one of the decisive issues that have been stated in its five-years development plans since the first one commenced in 1970. These plans involved several social goals among which is a massive reform of local agricultural sector with defined objectives to attain national food security through achieving self-sufficiency in several important crops and foodstuffs as well as to improve rural incomes (Al-Sheikh 2019; Metz 1992). Since then, the Saudi government has been generously supporting the sector with nonprofitable loans and other means (see Sect. 3.2) that boosted the foundation of large-scale farming firms implementing modern agricultural technologies (modern irrigation systems, greenhouses' agriculture, farm machineries, animals' farming, etc.). Meanwhile, attempts have been continued to sustain the traditional farming activities presented in the agricultural oases scattered over the country by enhancing their cultivation practices and services. This leads the domestic productions of numerous crops and foods (grains, fruits, vegetables, poultry products, milk and milk products, and others; see Sect. 3.3) to distinctly upsurge covering most of the local needs with some of them exceeding these needs resulting in their surplus to be exported (Al-Sheikh 2019; Metz 1992).

These strategic plans were targeted the Kingdom's needs to be self-dependent in some important food products assuring its free decision as well as supporting the social stability, taking into considerations full control and efficient utilizations of natural resources (Al-Sheikh 2019). Yet, full partnership with other friendly counters to provide the locally unproduced food products is also deemed, as no country can provide its full food requirements (Al-Sheikh 2019). These plans were also visioned within integrated and well-connected objectives that depend on land, agricultural policies and farmer, offered loans and incentives, land free distribution, marketing, farming protection and scientific research, farming nationalization, large-scale agricultural firms, animal husbandry farms, factories of dairy and dairy products, poultry farms, fishing and fishers, food oil production, and date palm fruits and their products.

Furthermore, the KSA ambitious 2030 strategic vision, declared in detail on 25 April 2016 by the Royal Crown Prince Mohammad bin Salman, has also signified the national food security and sustainable natural resources. The vision generally comprises of three pillars, namely: a vibrant society, a thriving economy, and an ambitious nation. These pillars are subdivided into specifically various designated objectives that are crucially considered as a roadmap for the country's economic diversification, sustainable development, and social life flourishment. One of these vital objectives is to attain food security promoting the country to reach to a zero-hunger condition granting better life for everybody living in the Kingdom (vision2030 2023).

Therefore, the MEWA has formulated a food security strategy and its implementing plan in May 2018 (MEWA 2018). This strategy was approved by the Council of Ministers with the Decree no. 439 dated on 15/8/1439H (2019). The vision of this strategy is to provide safe and nutritious foods in both stable and emergency states to all residents of the KSA. The strategy has five main objectives, which are:

1. Achieving a sustainable domestic food production system.
2. Diversifying and stabilizing external food supply sources.
3. Ensuring access to safe and nutritious food to all KSA residents and promoting healthy and balanced eating habits.
4. Building food security resilience capabilities.

5. Institutionalizing food security at the national level and ensuring clear and accountable governance.

These objectives are divided into 11 strategic programs that have been appointed to specific teams branched from the main steering committee responsible about the strategy's implementation. This steering committee is headed by H.E. Minister of MEWA with representative members from other related ministers (Ministry of Interior (MI), Ministry of Finance (MF), Ministry of Commerce and Investment (MCI), Ministry of Municipal and Rural Affairs (MMRA), Ministry of Economic and Planning (MEP), Ministry of Health (MH), Ministry of Transportation (MT), and Ministry of Employment and Social Development (MESD)). In addition, the strategy has a secretary committee that is headed by H.E. Head of Saudi Grains Organization (SGO), deputy of steering committee, with representative members from MEWA, MF, MMRA, MH, MCI, MESD, MEP, Food and Drug General Authority (FDGA), General Seaport Authority (GSA), Public Defense of the MI, Unit of National Risks (UNR), the Saudi Agricultural and Livestock Investment Company (SALIC), and ADF. Within its limits of implementing plan, the strategy has been based on ten key items, which are as follows:

1. Evaluating the real status of food security in the KSA.
2. A strategic food reserve and storage.
3. A governance system integrating the collaboration between all related sectors and authorities.
4. A system of food security early alarm including an information system of agricultural markets.
5. National program to reduce food losses and wastes.
6. National policy of food trade and import, agreement and regulation with targeted countries.
7. Systematic analysis of the Saudi Grains Organization and other related organizations of food security to determine their strength, weakness, and required improvement points.
8. Training and awareness program employing all issues of food security and nutrition.
9. A strategy to enhance the KSA external agricultural investment.
10. Enhancing the KSA participations in committees, agreements, and treaties related to food security.

The key principals of the strategy focus on an effective participation of qualified private sector as well as on a risk management that depends on the type of risk. This involves four items as the followings:

1. An efficient engagement of skilled private sector.
2. Risks' management on basis of its type.
3. An integrated food security system.
4. Notarized coordination with all related authorities.

This strategy is planned for 15 years starting from 2017 to 2030 with a budget totaling SAR 12.72 billion (about US$ 3.4 billion). The budget will be divided into three segments of 5 years/each (SAR 3.67, 4.53, and 4.52 billion, respectively). The infrastructure and funding incentives have been designated with the major portion of the first 5 years expenditures.

As indicated earlier (Sect. 3.3), the agricultural sector of the KSA has therefore attained numerous achievements in various locally produced food products that have enhanced the country to effectively provide major portions of its food requirements. The MEWA reported that the Kingdom has generally managed to locally provide about 30% of its food requirements; successfully surpassed self-sufficiency in some food products, among which are fresh milk (122%), table eggs (155%), and dates (115%); and positively attained considerable shares in other products, such as: vegetables (75%), chicken's meats (60%), fruits (40%), and fisheries (37%) (MEWA 2019a, 2020b).

Nevertheless, it is believed that the country has substantial opportunities to produce more foods, taking into considerations the marked potentials of the above-mentioned national related agricultural resources (Sect. 2.5) that are thought to be under-utilized. For example, the FAO (2019) land use statistical data revealed that the total arable land of the KSA is 80.75% ($1.74 \times 10^8$ ha) of the total country's area ($2.15 \times 10^8$ ha) (FAOSTAT 2022). This area of arable land consists of those under permanent meadows and pastures ($1.70 \times 10^8$ ha, 79.08%) and agricultural land ($3.60 \times 10^6$ ha, 1.67%) that includes cultivated land ($3.44 \times 10^6$ ha, 1.60%) and land under permanent crops ($1.57 \times 10^5$ ha, 0.07%).

As a vital part of the food security strategy, the Saudi government has also executed a policy to invest overseas in some friendly countries that own better agricultural capacities with little financial resources (Al-Obaid 2010; Fiaz et al. 2018; Luyt et al. 2013). This policy was intended to complement the local food productions enhancing food security and to ease the environmental stresses on the national natural resources. In 2008, the Custodian of the Two Holy Mosques King Abdullah has launched an initiative entitled "King Abdullah's Initiative for Saudi Agricultural Investment Abroad". This initiative urged the private Saudi firms to invest overseas by providing them with funds, credits, and logistics. Thus, they can be engaged in agricultural productions to support the establishment of the KSA's strategic reserve of food products to meet its requirements and to avoid any future food crisis. The initiative was initially funded by SAR 3 billion (US$ 800 million) by the Saudi government (Fiaz et al. 2018). The main objectives of the initiative are to sustain the Saudi food security, to enhance international food security, and to promote the Saudi private investors to employ their resources and experiences abroad (Al-Obaid 2010).

The initiative targeted several countries in Asia (Turkey, Kazakhstan, Philippines, and Vietnam), Africa (Egypt, Sudan, and Ethiopia), Europe (Ukraine) and Latin America (Brazil) (Al-Obaid 2010; Luyt et al. 2013). Nonetheless, countries with high agricultural potential are also considered. The strategic agricultural products that are sponsored by the Saudi government are wheat, barley, rice, maize, soyabean, oilseeds, sugar, sorghum, green fodders, live stocks, fisheries, and any staple product (Alamri and Al-Duwais 2019; Al-Obaid 2010).

Another initiative is the Saudi Agricultural and Livestock Investment Company (SALIC) that was established by the Royal decree no. M/22 dated 18/4/1430 AH (14/4/2009) as a Saudi joint-stock company owned 100% by the Public Investment Fund (PIF) of the Kingdom of Saudi Arabia (SALIC-Home Page, https://salic.com/). This initiative is intended to invest inside the Kingdom as well as overseas contributing to the food security strategy by providing food products and steadying their prices. Its activities are via instituting branch companies or via national, regional, and international partnerships. It has already started its activities in 2012 locally with the National Grain Company, ALMARAI, NADEC and fisheries as well as overseas with several global firms from various countries including Ukraine, Canada, India, Brazil Australia, Singapore, and UK (https://salic.com/). These firms were dealing with agriculture, grain trading, productions of rice and meat. It has initiated its obligations with a capital of SAR 4.8 billion (US$ 1.28) (PIF 2022).

Food imports play a primary role to achieving food security in countries (KSA) with factors limiting (severe climate, limited cultivable land resources or dearth agricultural water reserves) local food productions to meet national requirements. It is though worthwhile to emphasize that heavily reliance on such tactic is occasionally encountered with a variety of challenges that must be cautiously accounted. These challenges comprise considerable financial obligations on the national economic of the investing country resulting from capital flow, lack of self-control on imported food quality and quantity, fluctuations in international food prices, political conflicts or wars linked with host country, and negative impact on prices of locally produced foods impacting their production (Alnafiss 2017; Al-Sheikh 2019; Elmi et al. 2016; Jaworska 2018; Shabbir 2013; Tandon et al. 2017).

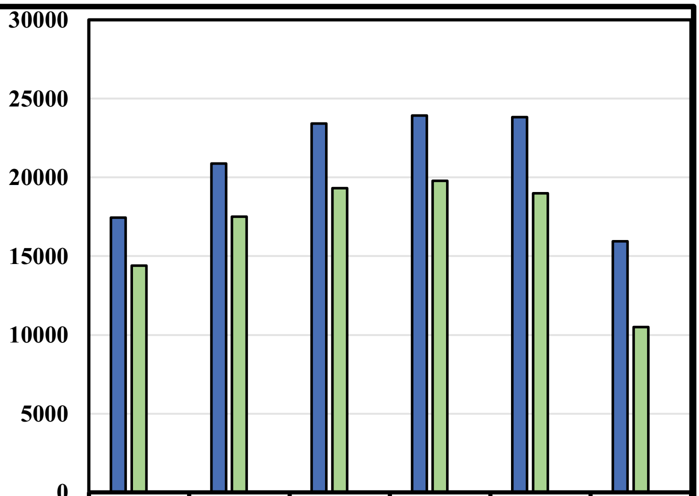
In addition, buying agricultural lands as a step of an abroad investment as adopted by several rich countries (KSA, Arab Gulf states, industrialized countries, etc.) might be challenged by the growing movement of so called “land grabs”, mostly among African countries (Cooke 2016; Cotula et al. 2009). It was also claimed that the competition between these rich countries is another serious challenge ought to be considered (Cooke 2016; Yan and He 2021). Furthermore, other investigators cautioned that 100% dependence on food imports may expose the country to the unplanned variations in global policies of prices, exports, and supplies (Ahmed et al. 2013; Elmi et al. 2016). Elmi et al. (2016) suggested that the risk of food import can be compensated by two effective tactics that include securing strategic grain stock and boosting the domestic productions. The authors also add that boosting local productions may necessitate a capital investment to adopt farming technologies, modern agricultural systems, and trained labors. This implies that domestic food productions are of a great value to avoid the heavily dependence on food imports and to strategically sustain national food security.

However, it is trustworthy to indicate that the KSA is currently considered as a food secure country (Alnafiss 2017; Al Muhana 2021; Ben Hassen and El Bilali 2019; Chatham House 2013; Lovelle 2015). This is due to the governmental generous expenditures, policies, and commitments to strategically achieve the national food security. Chatham House (2013) indicated that the KSA is a food secure country due to its strong economic stability and foreign reserves that support agricultural abroad investments to complement domestic food products for public consumptions. Chatham House (2013) also added that the Kingdom spends only 4% of its foreign currency on food imports. Also, Alnafiss (2017) implied that the high level of revenue in the KSA is one of the advantages keeping the residents food secured. Ben Hassen and El Bilali (2019) added that the KSA, as one of the GCC states, is a capital rich country having no foreign exchange restrictions that makes it less vulnerable to price threat as well as to overpass the deficit in its domestic production. In the meantime, and due to the challenging issues, it is also significant to disclose that the KSA has to endeavor an approach to guarantee food security that defies and demands prudent combinations of policies, private initiatives, and exploring further effective agricultural techniques to locally produce more foods to meet its needs (Kamal 2014).

### *4.3 KSA Food Security Challenges and Suggestions*

The sustainability of the KSA food security is challenged by serious issues, some of which are pertinent with the domestic food productions and the others are associated with the imported foods. As previously indicated in Sect. 4.2, the local food production coves about 30% of KSA total food requirements, whilst the rest being imported from outside. The challenges affecting the imported foods are already pinpointed in Sect. 4.2. On the other hand, the shortness in the domestic productions results from various restraints faltering the country's agricultural activities. These restraints are generally emanated from the unfavorable hot and dry climate, poor agricultural soils, and scarce water resources. These issues were also discussed earlier in Sects. 2.4, 2.5.1, and 2.5.2, respectively. In addition, several studies have reviewed the impacts of these restraints on the KSA agricultural activities and hence their roles in lessening the domestic food productions (Mallick et al. 2021; Almadini 2006; Alrwis et al. 2021; Ben Hassen and El Bilali 2019; Ghanim 2019; Kim and van der Beek 2018; Lovelle 2015; Rady et al. 2016; Sewilam and Nasr 2015).

Despite all of these, it is worth to further indicate that after instigating the national development plans in 1970 and with the unprecedented substantial governmental supports, the agricultural firms have become the foremost feature of the farming activities in the KSA, causing drastic extensions in the areas of cultivated lands being coincided with excessive consumptions of irrigation water. Numerous investigations pointed out that the agricultural sector consumes more than 80% of the total national water, as the most consuming sector of water in the country (Al-Ibrahim 1990, 1991; Baig et al. 2020; Chowdhury and Al-Zahrani 2015; Drewes et al. 2012; Ghanim 2019; MAW 1984; Rady et al. 2016). Figure 16 shows the agricultural water consumption from 2010 to 2019 as compared to the total water consumption in the KSA (Water 2021). It may be noticed from the figure that such high-water consumption by agricultural sector was in an ascending trend till the year of 2016 after which it started declining.




| | 2010 | 2012 | 2014 | 2016 | 2019 | 2019 |
|---|---|---|---|---|---|---|
| Total (BCM) | 17447 | 20884 | 23416 | 23934 | 23828 | 15939 |
| Agriculture (BCM) | 14410 | 17514 | 19312 | 19789 | 19000 | 10500 |
| % | 82.59 | 83.86 | 83.75 | 82.68 | 79.74 | 68.21 |

**Fig. 16** The percentage of KSA water consumption by agricultural sector in respect to total water consumption during the period between 2010 and 2019 (Water 2021)

The irrigation water is mainly provided from the unrenewable fossil groundwater resources, triggering severe depletion to such valuable resources (Ghanim 2019; Hamed et al. 2015; Sewilam and Nasr 2015). Furthermore, various studies have predicted that the fossil groundwater level will continue to drop down as such water consumption trend continues (DeNicola et al. 2015; Gabr et al. 2020; Ghanim 2019; Gutub et al. 2013; Ouda 2014a, b), concluding the real needs to implement some conservative steps to sustain these precious water resources. Thus, the legislative authorities have taken a variety of steps to protect these water resources through reducing the cultivation area of high-water consuming crops (wheat and forage), promoting water-saving irrigation practices, implementing comparative advantage techniques of growing high value crops in variable locations, enforcing water rights resources, and planning the monitoring systems and control of water abstraction (quotas, licenses, measurements, and fees) (MEWA 2019b). These implemented steps have attributed to the decline in irrigation water consumptions since 2016 to less than 70% (Fig. 14). However, all these steps to sustain the groundwater resources impose some impacts on local food production in quota as well as in future development that will affect the national food security.

# 5 Climate Change

## 5.1 Climate Change Definition and Concept

Climate change is an environmental issue of global concerns due to its direct and indirect effects on human lives and the surrounding ecosystems. The United Nations Framework Convention on Climate Change (UNFCCC) defined climate change as "a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (UNFCCC 1992). Also, the Intergovernmental Panel on Climate Change (IPCC 2007) referred to the climate change as: "a change in the state of the climate that can be identified (using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer". Ishaq-ur-Rahman (2013) said that climate change implies a long-term change in the statistical distribution of weather patterns (temperature, precipitation, and others) over a time periods of decades to millions of years. Werndl (2016) in addition argued that climate change is dependent on our knowledge, referring to that there is a climate change when there are distinct climatic distributions for two successive periods of time, taking into consideration that the choice of the time interval is influenced by the research purposes.

Climate change is induced by natural variabilities (volcanic activities, earthquakes, etc.) and human activities (deforestation, desertification, emission of greenhouse gases (GHG) [carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), and fluorinated gases, including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride ($SF_6$)], etc.) (IPCC 2007; Ishaq-ur-Rahman 2013; UNFCCC 2006, 2007). The climate changes are plausibly observed through the rises in global temperatures (atmospheric air and ocean water), precipitation rates, melted covers of snow and ice, and sea level averages (IPCC 2007, 2021; Ishaq-ur-Rahman 2013; UNFCCC 2006). The rises in global temperatures (referred to global warming) have already shown various effects on watersheds and ecosystems in several parts of the World (UNFCCC 2006). Besides the rises in the average of temperatures and precipitations, the global warming also increases the incidences of floods, droughts, heat waves, and severe typhoons and hurricanes.

Reports stated that temperatures of the atmosphere, ocean, and land have been indisputably increased due to human activities that led to extensive and rapid alterations in the atmosphere, ocean, cryosphere, and biosphere (IPCC 2007, 2021). The GHG concentrations in the atmosphere have persisted to increase since 2011, reaching in 2019 annual averages of 410 parts per million (ppm) for $CO_2$, 1866 parts per billion (ppb) for $CH_4$, and 332 ppb for $N_2O$, with land and ocean taken up a global near-constant rate of about 56% per year of $CO_2$ emissions from these activities over the past 6 decades, bearing in mind the regional variations (IPCC 2021). It was also reported that human activities caused an increase in global averaged precipitation over land since 1950 (with a faster increase rate since 1980s), a rise in mean sea level (01.5–0.25, annual average 0.20 m) between 1901 and 2019, and an increase in upper ocean (0–700 m) temperature since 1970s that decreased the Arctic Sea ice area between 1979–1988 and 2010–2019 (IPCC 2021). Finally, it deserves to emphasize that the damaging severity of climate change induced by humans depends on both its current magnitude as well as its future irreversible potential according to Solomon et al. (2009), who also pointed out that the latter process is a long-term one that may take centuries after correcting the existing GHG emissions.

### *5.2 Climate Change Impact on Agricultural Productions and Food Security*

The successful growth and optimum productions of growing crops depend on both biotic factors (genetic, diseases, etc.) and abiotic factors (appropriate climatic variabilities, suitable soil properties, irrigation water availability, proper farming practices, etc.) (Baker and Capel 2011; Chen et al. 2015; Gent 2017; Kurtener and Krueger 2014; Liliane and Charles 2020). The climate variabilities affecting crops comprise mainly of atmospheric $CO_2$, temperature, precipitation, solar radiation, wind, and humidity (Aggarwal 2009; Kurtener and Krueger 2014; Liliane and Charles 2020). Though, these climatic variabilities are necessary for the growth of plants and their productivities, they have been crucially affected by the climate change processes (IPCC 2007, 2021; UNFCCC 2006; Van Dijk et al. 2022), with agricultural activities contributing noticeable inputs. EEA (2015) indicated that agriculture accounted for 10% of the EUs' total GHG emissions in 2012 after being reduced 24% from 1990 to 2012, due to declining livestock numbers, efficiently utilizing fertilizers, and properly managing manure. Yet, between 2001 and 2011, the GHG emissions from crop and livestock production increased by 14% in the rest of the World, having most of it occurring in developing countries because of rises in agricultural outputs.

Several investigators suggested that climate change causes serious impacts on crop growth and productions (Auffhammer et al. 2012; Liaqat et al. 2022; Lin et al. 2020; Nelson et al. 2009; Sinnarong et al. 2022). Nelson et al. (2009) revealed that the climate change causes a thrilling impact on agricultural productions of growing crops, as high temperatures reduce yields and encourage propagation of weeds and pests, whilst inconsistent rainfall patterns increase the probability of short-run crop failures and long-run yield declines. Auffhammer et al. (2012) indicated that statistical analysis of data at Indian state level confirmed that drought resulting from inconsistent monsoon and lower rain as well as warmer nights decreased rice yields affecting hundreds of millions of rice producers and consumers in the country. Sinnarong et al. (2022) using unit root tests and feasible generalized least squares implying a panel data model to estimate insurance schemes due to climate change for years of 2030, 2060, and 2090 concluded that both primary weather variables of temperature and rainfall have significant risk reduction performances of 8.14–13.37% for rice, 2.43–6.48% for oil palm and 8.89–14.13% for rubber tree, respectively.

Results of the investigation conducted in three major islands of the Mediterranean basin (Sicily, Crete, and Cyprus) on annual (wheat, barley, tomato, and potato) and perennial (grapevine and olive tree) crops to evaluate climate change impacts using an adoption technique of a set of performance calibrated models showed that adopting certain farming strategies (sowing time and growing season length) may counter-balance the effects of rising temperature reducing biomass accumulation time and the lower rainfall rate boosting water stress, having into considerations the positive effect of $CO_2$ concentrations on both photosynthesis and transpiration (Moriondo et al. 2021). This may imply that there are spatial variations in climate change effects on crop productions that might be balanced by adopting proper farming practices accordingly lessening its impact on food production.

Such adverse impact of climate change on agriculture and its productions will eventually put pressures on the attainment food security. Liaqat et al. (2022) suggested that the atmospheric rises in $CO_2$ levels enhance plants' photosynthesis and hence productivity; yet this enhancement will be counteracted by the undesirable effects of $CO_2$ rises through increasing evapotranspiration, drought, floods, erratic precipitation, pest infestation, and demands of irrigation water. Nelson et al. (2009) proposed that though climate change might cause a variety of gains in certain crops in some regions of the World, its inclusive impact on agricultural productions is projected to be negative that will jeopardize the global food security. The authors attributed that to the anticipated increases in food prices resulting from the reduction in food productions. Tripathi et al. (2016) indicated that the adverse effects of climate change on agricultural productions are challenging the global food security in both quantity and quality, as they will impose immense pressure on various food products (wheat, rice, corn, vegetables, fruits, and fisheries). The authors also added that this process is particularly complex to identify due to the interactions involved at every phase of life cycle of any food source.

El Bilali et al. (2020) suggested that climate change will impact food security in four prime dimensions that are food availability, food accessibility, food consumption pattern, and food stability, inferring that the interact relation between both subjects makes the case of integrated policy interests maximizing mutual benefits when trade-offs addressed. The authors also proposed that all strategies for climate change mitigation and/or adaptation should seriously take into considerations not to threaten efforts for ending hunger and eradicating any form of malnutrition that are in the implementation plan of the 2030 Agenda for Sustainable Development of the United Nations.

George et al. (2015) indicated that the food systems are affected by climate change in several ways varying from direct effects on crop productions (reducing yield quantity and quality, extending length of growing season, etc.) to indirect effects (altering food markets, prices, supply chains, etc.), meaning that the climate change forms an extra issue to the concerns of attaining food security for all. The authors further concluded that climate change is one of various factors affecting food systems and its impact on them varies between regions as well as between societies within a region, signifying that acclimatizing food systems with climate change is possible through intervening their availability, accessibility, and utilization. Finally, it is also recommended that combating impacts of climate change on food security is achievable through adopting good farming management that employ some changes in cultivation practices (selecting varieties, pest control, optimizing farming pattern, minimizing food waste, etc.) competent with the regional climate change (Aggarwal et al. 2018, 2019; Campbell et al. 2016; Habib-ur-Rahman et al. 2022; Islam et al. 2016; Lal 2022; Mirzaei et al. 2021).

### *5.3 Climate Change Impact on Food Security in KSA*

The Kingdom of Saudi Arabia is well characterized by its tropical and subtropical desert climate featured with extreme heat and aridity that is coincided with high temperatures in daytimes and low ones in nighttime with a dearth rainfall, except in the southwestern area (please, see Sect. 2.4). As other countries in the World, the Kingdom is also affected by the climate change. Several studies concluded that the climate variables are undergoing several variations in the KSA. Odnoletkova and Patzek (2021) analyzed the past climate change (temperature trends and extreme temperature events) including most recent years (from 1979 to 2019), with summer trends (June–August) being appraised individually from the annual ones. The authors have realized that KSA is experiencing a strong warming trend, having summer temperatures rising faster than all-year. Over the last 4 decades, the rate of warming in the KSA was 50% higher than the remainder of the north hemisphere landmass. As a result, air humidity (air moisture content) had significantly increased in the country. Increases in both temperature and humidity had ascended the dewpoint temperature and hence thermal discomfort throughout the country. Such increases are more extensive during summer seasons, which are already hot compared with winters.

Tarawneh and Chowdhury (2018) studied future trends of temperature and rainfall for several regions in KSA, using linear and Mann–Kendall analysis and NCAR Community Climate System Model for the periods of 2025–2044, 2045–2064, and 2065–2084 as compared with the reference period of 1986–2005. They found that the temperature will increase in ranges of 0.8–1.6 °C, 0.9–2.7 °C, and 0.7–4.1 °C, respectively, with the highest increases were in the Central and Northern regions. Meanwhile, rainfall values showed variable patterns, with significant increase in the Southwestern and Western regions. The regional differences in both variables were significant, implying the need for regional-specific plans to mitigate climate change impacts.

Chowdhury et al. (2016a) indicated that climate change has negative effects on crop water requirement (CWR) in Al-Jouf region (located in the northwest), causing an increase in CWR from 873 million cubic meter (MCM) in 2011 to 931 MCM in 2050 because of predicted 1°C increase (2.9% annual increase of CWR). These findings signify the need for a good planning for water resources management in the area, particularly fossil groundwater is the main resource for irrigation. In another study, Chowdhury and Al-Zahrani (2016) predicated that an increase of 1 °C between years of 2011 and 2050 would increase the CWR for the country by 11.9 MCM (8713 and 9176 MCM, respectively), an amount of water sufficient to produce about 4900 tons of wheat per year. For the same years, the predicted CWR increases for dates, alfalfa, and wheat were in ranges of 3.3–11.9%, 3.3–12.1%, and 3.9–15.6%, respectively. The overall annual increase of CWR is about 1.8–2.9% in the KSA, insinuating the need for a well-planned national strategy to conserve water utilized for irrigation purposes.

Alam et al. (2011) in their study forecasting future climate change (temperature and precipitation) to the end of the century and their impact on production of wheat, barely, dates, vegetable, and maize indicated that the daily average temperature and annual precipitation are expected to increase from 3.0°C to 4.2°C and from 9.8 mm to 37 mm, respectively. The predicted increases in temperature and precipitation also varied from a region to another. These changes in climate will reduce the yield of tested crops, with the changes in temperature causing greater effects than precipitation. Declines in yield of wheat, barely, and dates may exceed 40% as compared with current values. Haque and Khan (2022) also observed a significant rise in temperature by 1.9°C in the 50 years extending between 1967 and 2016, with summer owning greatest rise. Yet, changes in rainfall were insignificant. These results showed an increase 1°C will reduce crop yields by values ranging between 7 and 25%. The obtained results also indicate that rainfall positively affect crops, but could not offset the temperature adverse effects.

It could be concluded from these studies that Saudi Arabia is impacted by climate change as other countries in the World. This climate change has a substantial negative impact on the food security in the country that relies on food import, as indicated earlier (please, see Sects. 4.2 and 4.3). Rahman et al. (2022) emphasized that climate change in KSA retains a considerable impact on the already fragile food supply system and challenges in the future might be greatly striking. Alkolibi (2002) deduced that climate change is adversely affecting KSA, proposing a ‘no regret’ policy to be implemented in order to safeguard the country from further unfavorable effects, especially on agriculture and water supply. It is therefore noteworthy to reiterate the concerns related to climate change and its impact on food security attainment in the KSA, taking into considerations its effects on agricultural productions as well as water resources that are scarcely limited in the country and one of the major limiting factors to agricultural development in the country.

## 6 Conclusion and Prospects

In this chapter, various insights towards the themes of food security and climate change and their interrelated impacts on the Kingdom of Saudi Arabia were discussed. It is crucially believed that discussing such topics are worthwhile due to their global concerns in general and the Saudi government’s efforts in particular to cope with them. As a wealthy country, Saudi Arabia is considered a food secured nation. However, it depends predominantly on the policy of imported foods (70%) to achieve such status. The success of this policy nonetheless depends considerably on fickle factors (international food prices, political relations as well as conflicts, stability of exporting country, etc.) that make such policy is fragile and untrustworthy.

It is therefore assumed that relying on local food productions is a better policy and more reliable option. However, the Saudi food productions are encountered by barriers related to its harsh climate (desert climate with extreme heat and aridity) and its distinctive national resources (scarce and meager irrigation water as well as saline soils). With these circumstances, this option is however conceivable. It inquires a policy that employs a national strategy based on good integrated scientific management practices that maximize the local food productions and sustain the national natural resources via their efficient utilization. It is also noteworthy to point out that the KSA occupies a vast area experiencing noticeable variations in its climate as well in its natural resources, which will plausibly empower the success of this proposed strategy.

Climate change is a global issue that international authorities and organizations are markedly concerned about. Such concerns are attributed to its detrimental impacts on human lives and the surrounding environment and its components. These unfavorable impacts are perceived, for example, in rising temperatures, irregular rainfall and floods, dust winds, increasing atmospheric GHGs' concentrations, and others. This climate change is also observed to be affected by anthropogenic activities, among which is agriculture. Meanwhile, the climate change will negatively influence the crops' growth and development and hence reducing their productivity that eventually will undesirably influence food security. Also, it ought to mention that worldwide population is in ascending, putting more stresses on worldwide food productions, exacerbating the global food security status.

Alike other countries in the World, Saudi Arabia is affected by the changes in climate. Studies observed noticeable alterations in the climatic variables, such as rising temperatures, erratic precipitations, which depicted to negatively impact crop water requirements and groundwater resources. As a results, food security will be adversely influenced by these changes in the climatic variables. Though, the Saudi authorities have already employed several actions to cope with these climatic changes, further actions are well advocated to sustain the national food security and the current success attained in this matter. Among the recommended actions are the followings:

- Employing regional relative incentive farming that considers the variations in climate condition, cultivated soil quality, irrigation water availability, etc.
- Adopting modern farming technologies (breeding and planting heat and drought stress-tolerant varieties, advanced irrigation systems, integrated water management, etc.).
- Applying global agricultural practices after being adapted to the Saudi farming conditions.

- Raising awareness of farmers towards climate change and its consequences on the country's natural resources via widespread and intensive agricultural extension programs.
- Improving the perceptions of people living in the country towards the food security and their roles in sustaining it.

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# Chapter 10
# Sustainable Management of Food Waste in Saudi Arabia

**Shahrah S. AlQahtani, Ezzat Khan, Adam E. Ahmed, and Meshabbab A. AlQahtani**

**Abstract** Food waste management, FWM is essential factor that is firmly related to environment and creates several issues throughout the globe. Food waste, FW is a global threatening subject for food systems. Because of inadequate infrastructure and techniques, many countries are facing difficulties in judicious management of FW. Comprehensive definition of the term "food wastage" (Food Waste, Food loss, and food surplus) with clear classification (Avoidable, Nonavoidable, unplanned, planned food waste and post-harvest food waste) is elaborated. It helps to distinguish wasted food at all stages of food supply chain (FSC), which needs to be addressed and managed. Likewise, a brief discussion about Saudi Arabia (among the top food wasters) is included and some of the challenges that may cause the gaps in

S. S. AlQahtani (✉)
Department of Environment and Sustainable Development, College of Science, University of Bahrain, Sakhir 32038, Kingdom of Bahrain
e-mail: shahrah_saad@outlook.sa; 202012465@stu.uob.edu.bh

E. Khan
Department of Chemistry, College of Science, University of Bahrain, Sakhir 32038, Kingdom of Bahrain

Department of Chemistry, University of Malakand, Chakdara, Lower Dir 18800, Khyber Pakhtunkhwa, Pakistan

E. Khan
e-mail: ezkhan@uob.edu.bh

A. E. Ahmed
Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: ayassin@kfu.edu.sa; adamelhag2002@yahoo.com

Department of Agricultural Economics, Faculty of Agriculture, University of Khartoum, Khartoum, Sudan

M. A. AlQahtani
Independent Researcher, Khobar 34715, Saudi Arabia
e-mail: meshabbab@outlook.com; meshabbab@hotmail.com

 
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the management have also been discussed in some specific cases. The potential environmental impacts of food waste and its treatment techniques have also been highlighted to identify gaps and hotspots in food waste management. Besides, the article suggests some strategies to tackle food loss/waste by applying zero hunger strategy, sustainable management, legislations and strict laws, and circular bioeconomy. Also, some recommendations to strengthen the role of food waste management has been addressed at the end.

**Keywords** Environmental impacts · Food waste · Food loss · Sustainable management · Zero hunger

## 1 Introduction

Food waste is one of the major environmental issues and unstructured problem because of stranded circumstances of identifying the causes and effects of the subject issue (Närvänen, Mesiranta, Mattila, and Heikkinen 2019). According to Food and Agriculture Organization (FAO) more than 850 million people globally could not access to their needed food. An estimated amount, 1.3 billion tons of food is wasted annually, causing a huge loss of USD 900 billion to global economy (Mirza B Baig, Al-Zahrani, Schneider, Straquadine, and Mourad, 2019a, b). Food waste occurs at various stages of FSC, depending upon the situation, available facilities, locality/country, and management. It can be post-harvested, during transportation, during storage or at the end of the FSC. There seems to be a terminology problem to define food wastage. Many authors have attempted to address the issue, (FAO 2011; Huang et al. 2020) and they consider food loss is occurring at primary stage of FSC during post-harvest processing of agricultural products before retail. However, it becomes more serious in terms of price when considered at the end of the FSC during retail and consumption (Corrado et al. 2019; Huang et al. 2020). In developed countries like Germany, Italy, US, Japan and several other, more than 40% of food is wasted at the retail and consumption stages which is enough to cover three times the globe's hunger. On the other hand, in developing countries most of the food wastage occurs at the post-harvest and processing stages due to limited resources (Huang et al. 2020; Xue et al. 2017). Continuous efforts have been made to create awareness in the society to prevent food waste, it reveals that in 2007 the food waste estimate was 11.6 million tons, and it was reduced to 10 Mt in 2015 (FAO 2017). Whereas, till 2025 food waste is estimated to rise annually which means recent regulations and policies are not enough or practical to reduce the food waste to reach food security and sustainability. Some authors have classified food loss and waste, based on edibility or inedibility, avoidability or unavoidability (Närvänen et al. 2019). Understanding the definitions based on edible and inedible parts of the food may help the decision-makers to implement appropriate processes and strategies to improve the role of food wastage management (Corrado et al. 2019).

The total municipal wastage in Saudi Arabia is produced from the three main cities Riyadh, Jeddah and Dammam is 40% of the total (Bashraheel 2020). The food wastage harms the environment, it also destructively affects the natural resources such as land, energy and water that have been used during the food production (Grizzetti et al. 2013). Furthermore, it is authentically linked to health problems such as obesity, diabetic, and hypertension issues which reaches 59.4%, 23.9%, and 40.5%, respectively of Saudi's population. The Saudi's officials encourage and increase the waste recycling up to 42% with reducing 82% of the overall waste divert to landfills (Bashraheel 2020). Under the umbrella of Saudi's vision 2030, food wastage management team is working hard to setup doable standards and procedures for sustainability and catch up the rest of devoted countries to protect the earth (Bashraheel 2020).

The purpose of this study is, to propose comprehensive definition of food waste and loss and discuss adverse effects of food loss/waste on environment and natural ecosystem. Moreover, it provides different strategies and some future recommendations to overcome FW/L and enhance the FWM. The graphical framework and the key element of the entire study is summarized in Fig. 1.

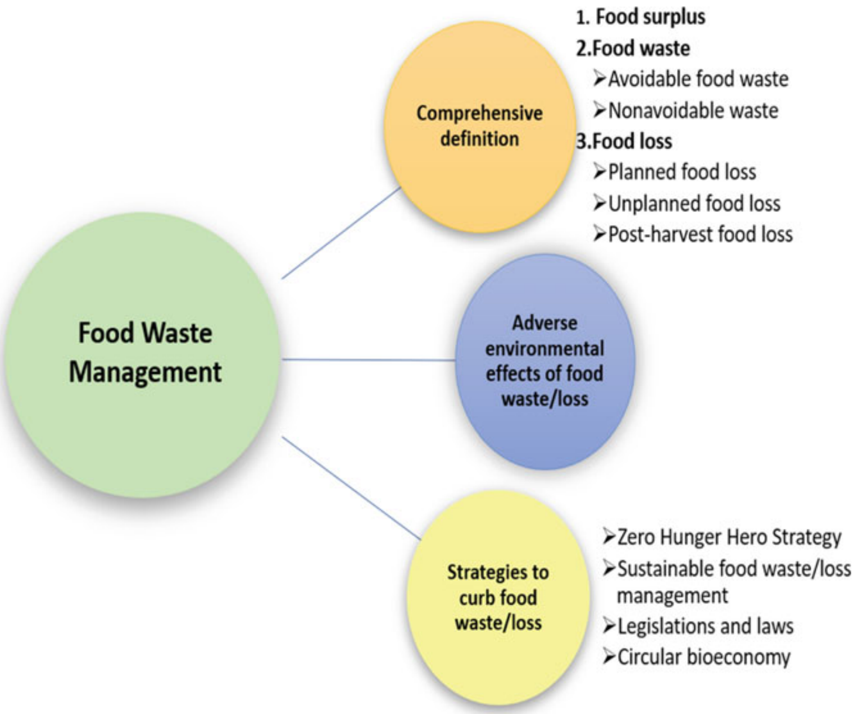


**Fig. 1** The schematic representation of main topics covered in this study. Constructed by the Author

## 2 Food Wastage, a Controversy in Its Definition

There is a controversy in definitions of various terms related to food waste, the matter has not been seriously considered except from a very recent report (Teigiserova et al. 2020). The food waste varies in how to be managed in many countries due to unclear food waste terminology, and it is challenging to compare all the systematic research results of food waste (Huang et al. 2020). On the basis of lack of clear definition, the sustainable management of food—waste is somewhat difficult. The abovementioned reports cover the topic in a comprehensive way and six categories of food have been elaborated, namely, (i) edible, (ii) naturally inedible, (iii) industrial residue, (iv) inedible due to natural causes, (v) inedible due to ineffective management and (vi) not accounted for (Teigiserova et al. 2020). These six categories reorder the food wastage hierarchy to support a circular bioeconomy depending on whether the food can be consumed or not. Category 1 surplus food, includes all edible food, is the greatest choice for both source protection and human consumption (reuse) in FWM. Source protection and human consumption are best served by this method; category II-V food waste includes all inedible food for any cause or any reason at all: bones, leaves, pomace, crops that have been damaged or neglected and it prioritize for biorefinery and recycling (compost, animal feed etc.) as the environmental option in food wastage pyramid; and category VI food losses that is disposed to landfills or incineration as the least preferable option in the pyramid (Teigiserova et al. 2020). If wastage of food is categorized into specific groups, it makes the food wastage analysis straightforward to improve and monitor wastage management. Globally, there is a major gap in the recognition and classification of terms like food loss, food waste, and food surplus which is wasted or lost over half of the produced food before and after it reaches human consumption. The FAO defines food loss as, "any decrease in the amount of food in the food supply chain". Not all food wastage can be considered food loss, it refers to the food that is intended for human consumption but is not properly consumed. It's not obvious, when food loss becomes waste (FAO 2014; Isah and Ozbay 2020; Kibler et al. 2018). The following section describes various terminology of food wastage generation. The food wastage is classified into three main and common terms regarding to the food supply chain (FSC): (i) food surplus, (ii) food waste includes (avoidable and non-avoidable) and (iii) food loss includes (planned, unplanned, and post-harvest) which are elaborated as below.

### *2.1 Food Surplus*

It is the amount of food made available or produced in excess of the people needs and demand. It reflects an overproduction of food in agricultural processes or represents the extra amounts of imported agricultural products through the government organizations. Post-harvest, oversupply, and inedible foods are wastage channels before reaching to suppliers and consumers and is considered the food surplus category as well. Further, food production can be changed in some circumstances and from year to year according to the climate and economics effects that include market prices impacting farmers' choices of crops. However, food surplus may help offset the food deficits and enhance achieving the food security. It is considered a laudable achievement because of reaching a level of food security to community needs, and it can accommodate economic benefits and food aid for humanitarian benefits. However, food surplus' term is not commonly used to describe this positive meaning (Atkins and Bowler 2016; Huang et al. 2020). The term food surplus is always confused with food wastage because it has sustainable method for tackling the food wastage management, and it may be used as a safeguard against food scarcity. The food surplus is considered as global environmental issue which does not eliminate the food deficits, especially, in developing countries. This big debate among the food wastage literatures is based on two gaps; between food production and consumption and the total current food availability and need by 2050. Therefore, comparing the food supply per capita with food availability at the market level reveals that in some developed countries, US and some European Union (EU) countries, the food surplus exceeds 1,000 kilocalories (kcal) per capita (Papargyropoulou et al. 2014).

## 2.2 *Types of Food Waste*

According to FAO, food waste is all the edible food that is going to human consumption, but it gets wasted at retail and consumption stages which can be found at the end (downstream) of the FSC (Al-Khateeb et al. 2021; FAO 2011; Garcia-Garcia et al. 2015; Kibler et al. 2018). Also, throwing food, that is still eatable, considers intended waste depending on public's behaviours and believes. For examples, uncalculated amount of purchased food for restaurants usage leads to food waste; purchasing a large quantity of greens by retailers for promotions, preparing massive meals for hospitality and special occasions, the expired food which the people think that it is nonedible anymore and in groceries the food under low demand which is usually disposed of (Huang et al. 2020; Papargyropoulou et al. 2014). According to Food Use for Social Innovation by Optimising Waste Prevention Strategies (FUSIONS) and the UK Waste and Resources Action Programme (WRAP), a food waste is any food that is wasted at the end of the food supply chain, including non-edible parts like peels, bones, or eggshells. This widens the definitions of FUSIONS and WRAP, making them more comprehensive (Garcia-Garcia et al. 2015). Because of the discrepancy in the definitions and considerations, the food wastecan be classified into two categories: avoidable and nonavoidable food waste. This classification might help to locate area of preventable waste and address food sustainable strategies for waste reductions (Papargyropoulou et al. 2014).

#### 2.2.1 Avoidable Food Waste

Based on WRAP definition, the avoidable food waste is the edible food that is discarded because of beyond need, leftovers, not attracting the consumers, or inedible food due to putrefaction. All the food that majority of human consumes through their beliefs and customs such as traditional practices, religious values, and individual choices included into avoidable category (GOV.UK 2017; Papargyropoulou et al. 2014). Elegant supermarkets take care of the food representation and what should look like and irregulated shape of the fruit and vegetables are getting wasted regardless to its nutritional values or remaining time to expiration (Science 2021). In the restaurants and food services industry, the avoidable wasted food can be generated at front-office (plate waste) and back-office (kitchen, packaging and storing) operations. For example, buffets, burn food, food and water spilled, overstocking and the way that has been used in preparing the meals (Martin-Rios et al. 2018).

#### 2.2.2 Nonavoidable Waste

The parts of the food that are produced as inedible under normal conditions during food services such as cooking, packing, and storing, including fruit peelings and meat bones, eyes, hairs, and coffee grounds come under the umbrella of this category (Bernstad et al. 2013; GOV.UK 2017; Papargyropoulou et al. 2014). Nonvoidable wasted food can be generated at front-office such as plate waste with eggshells or veggie skins and food trimmings or at back-office like packaging and equipment defects, food scraps to name as few examples (Martin-Rios et al. 2018).

### *2.3 Food Loss*

Food loss is the edible food that is spoiled (wasted) occurring at an early stage (upstream) of FSC depending on FAO definition (Al-Khateeb et al. 2021; FAO 2011; Garcia-Garcia et al. 2015). It is fortuity wastag during post-yield or transportation of agricultural processing, and it cannot be marketed because of pest invasions or improper storage ways (Huang et al. 2020). Food losses is strongly related to schemes that need investment in infrastructure (Papargyropoulou et al. 2014). FAO states that food waste and loss are considered only for products that come under human consumption, except parts of products that are inedible and suitable for animal feeding. Thus, the food is originally designed for human consumption, but unintentionally, it becomes unplanned inedible for human (FAO 2011; Papargyropoulou et al. 2014). Based on this discussion, food loss can be classified to two groups: unplanned and planned inedible loss and both of them relying on end-of-life destination of the food which is no longer involve in human food supply chain. There are environmental and marketing factors such as weather fluctuations, agricultural pest invasion, animal infectious disease, shortage of product in the market and increase in prices that differentiate between them (Garcia-Garcia et al. 2015; Spang et al. 2019). The planned and unplanned loss can be useful in achieve the environmental sustainability if local authorities valorise the loss and deal with them in smart way like using bioconversion and anaerobic digestion (AD) methods to convert the loss and waste to many types of bioenergy and fuel particularly, in developing countries that have financial constraints which lead to overcome high-cost of energy in their industrial drying systems by using the waste of fresh feedstocks. Moreover, it can be used as compost for agricultural lands or sending the loss to barns for animal feeding (FAO 2011; Spang et al. 2019). Fats, oils, and lignocelluloses (lignin, cellulose and hemicellulose) of food waste and loss are renewable sources of valuable chemicals and biorefinery. Green chemistry is combined with the FLW valorisation concept to produce chemicals from plant and animal biomass using environment friendly industrial conversion processes. Renewable chemistry has enormous advantages in terms of environmental safety, population health and energy efficiency. These benefits include waste prevention, the presence of new environmental chemicals lead to a reduction in the use of synthetic and toxic reagents, biodegradable product designs and processes, the presence of renewable materials, the use of catalysis instead of stoichiometric and pollution prevention methods. There is a variety of feedstocks that may be used to produce biofuels, such as biodiesel, biokerosene and natural gas, depending on the kind of biofuel the individual wishes to produce. Bioethanol production in Brazil is second in the world, behind only the United States. There is no need for oil imports, the market is stable and ethanol fuel may be used in all vehicles. Traditional bioethanol and biodiesel, both of which are derived from plants, have several disadvantages that renewable biofuels do not. More than 30% of the world's energy demands will meet by renewable biofuels by 2050. By then, annual production of biomass-based biodiesel would have risen to 21,463 million litres. There are three factors that make them appropriate for such conversion: a high hydrogen to carbon ratio and a high carbon bond saturation, as well as low water solubility. Additional benefits include high octane ratings reducing emissions of sulphur oxides, nitrogen oxides and particulates. This characteristics greatly support to minimise the quantity of pollution in the air (Isah and Ozbay 2020).

### 2.3.1 Planned Food Loss

When loss occurs intentionally through upstream stage, it would be considered as planned loss (FAO 2011; Spang et al. 2019). It plans to be used for other purposes as food for animal or insects (black soldier fly larvae). A study wherein four food loss disposal techniques have been compared: two of them have been used in South Korean wet pig feed and a dry pig feed as animal feeding style and two techniques used in United Kingdom (UK), anaerobic digestion and composting. Results showed that techniques used for animal feeding have better results and low environmental and health impacts in comparison to other two (Salemdeeb et al. 2017). The planned loss food can be a way to reduce accumulation of non-biodegradable packaging and address the food quality and safety issues, it also helps to avoid food-borne diseases and infection (Guillard et al. 2018; Science 2021). Globally, minimizing the environmental impacts and dependence on fossil fuel of food packaging with saving natural resources are goals to access the sustainability in food consumption. Using agro-food waste to generate biodegradable material is a promising innovation of waste-based food packaging and supporting green economy.

### 2.3.2 Unplanned Food Loss

It occurs unintentionally through upstream stage due to insufficient storage techniques and lack in cooling facilities as well as fridge truck defects or long-distance transportation. However, if we could shorten the chain of food processing, we could solve unplanned loss by encouraging urban farming (Science 2021; Spang et al. 2019). More than 50% of population live in urban cities and the food production and processing happen in rural farms. Rural farms are places to generate food for a huge population, and themselves they have easy access to fresh foods that is extremely limited in urban cities. Urban farming and growing food in modern cities reduce the dependency on long-distance food supplies and emissions that are produced during food transportation, processing and packaging (Science 2021). Thus, ensuring a healthy life of the people in urban areas who are benefiting from the fresh food. It is very important to have some arrangements for growing fresh food close to urban population so that long transportation and other associated issues are skipped.

### 2.3.3 Post-harvest Food Loss

Food loss can happen as post-harvest that reveals quantitative and qualitative loss at the production stage throughout handling, processing, storage and packaging phases (FAO 2011). Post-harvest loss is estimated around 2600 kilocalories (kcal) per capita per daily including animal feed and household waste (Papargyropoulou et al. 2014). In fact, when the raw products are harvested, there are many improper circumstances that impact the post-harvest and leads to increase the risk of losses such as, inadequate drying operations and storage efficiency, low quality materials of packaging, and inappropriate transportation facility. Furthermore, at the harvesting stage, processes and techniques that are machines or hand-picked can lead to losses. Furthermore, delaying in harvest causes exposing the grains to severe weather and pests which pushes a handsome amount of food to loss. The developing countries have the high levels of loss at post-harvest and at production stage, in contrast to developed countries, where it occurs at retails and consumption stage with an estimated quantity of > 20% of food loss. Mechanical harvesting is mostly used in developed countries for various commodities, while hand-picked is a common technique in developing countries, and it relies on labour's efforts that might take long time of harvesting causing more losses. The absence of investment in agricultural and Industrial drying systems leads to a major loss of food, compared to developed countries, that have greater features in food system and preparation including advanced automatic devices for food production and irrigation with storage and packaging solutions. These differences between the developed and developing countries have been helpful insights on post-harvest losses (Spang et al. 2019).

## 3 Food Waste in Saudi Arabia Challenges and Solutions

The food waste in KSA is 427 kg/cap/y, taking the country to top food waster on global level even in comparison to industrialist countries in Europe and North America (Baig et al. 2019a, b). According to an estimate based on questionnaire from 1135 restaurant consumers, 1/3rd of the imported food goes into waste because of lower shelf life and warm climatic conditions of the country (Mirza Barjees Baig et al. 2022). Conclusions derived from a computer-based study on 2454 respondents indicates that public awareness, food security, food waste management, encouraging investors are re-visiting regulations are necessary steps to minimize the waste and convert it into useful products (Althumiri et al. 2021). There are several factors which affect the amount of wastage generated in the country including social and religious factors, strong legislation, financial support, active participation of stakeholders which need to be explored with exact scientific view point (Elshaer et al. 2021). A huge amount of food is wasted in order to make room for new groceries, the companies responsible for importing food are lacking awareness, inappropriate planning and excess of food is supplied during social gatherings. This food can be converted into compost and can add approximately 70 million USD to the economy of the country (Waqas et al. 2018). Countries in Africa and Saudi Arabia are understudied in terms of food waste, and a challenge of food safety and sovereignty might be faced any time, by these countries (Oelofse et al. 2020).

In 2012 the estimated potentials of power production from food waste was 990.40 MW/y from incineration and RDF (refuse derived fuel) scenario and it was predicted to reach 2196.76 MW by 2025(Ouda et al. 2016). According to a study carried out in 2015, the country had a share of 50.6% (7.7 Mt/y, 0.7 kg/capita/day) food waste out of total municipal waste. It was estimated that the country can generate 2.99 TWh electricity through anaerobic digestion of the food waste (Nizami et al. 2015). A preliminary study regarding generation of biofuels reveals that Saudi Arab's and pilgrims population on the basis of 2017 data and by 2030 could produce 1.08–1.41 million tons of biodiesel and can add up to $ 72.71 million to the country's economy. This huge aid to the economy is only possible to divert landfill towards technological processings. The process of biodiesel production can face a challenge of waste collection, segregation, impurities, reactor design and at the end, the quality of the produced biodiesel (Rehan et al. 2018).

A scientific landfill strategy for food waste management in KSA was proposed, efficient collection of methane can generate considerable revenue and save the consumption of conventional fossil fuels (Anjum et al. 2016). Laboratory studies of food waste samples were carried out where 99% methane and 1% other gases ($NH_3$, CO, $H_2S$ and $SO_2$) were detected at a temperature less than 50 °C. Under these conditions a specific incubation period would be required for initiation of chemical degradation/gasification process, after 98 days maximum production of methane was observed. This study reveals that the environmental conditions of Saudi Arabia can positively support the process under normal condition and at even larger scale (Alruqaie and Alharbi 2012). Environmental sustainability in the country could be achieved only by installing bio-refineries as enshrined in country's vision 2030 (Mu'azu et al. 2019). Food waste can also be converted into $H_2$ gas as well as biofertilizer through certain chemical processes which are clean and more environment friendly (Khan and Kaneesamkandi 2013; Miandad et al. 2017).

Besides, technological management of food waste, it is extremely important to spread awareness among dwellers to participate in the noble cause. A study carried out on 199 University level female students gave encouraging results, which points at this aspect of the issue (Al-Zahrani and Baig 2014; Alsawah et al. 2022). Several other parallel steps have to be taken such as establishment of food banks, effective cold storages and surplus food redistribution etc. which can help minimizing the waste.

## 4 Adverse Environmental Effects of Food Loss/Waste

Food loss/waste has a negative impact on the environment such as it contributes to increase greenhouse gases and methane emissions which cause climate change, acidification, eutrophication of lakes, water and energy consumption, carcinogens to the soil, and land occupation. In this section, we will critically be discussed and compared various environmental potential impacts in the most common food waste treatment techniques such as landfills, incineration, anaerobic digestion, composting, animal feeding, and heat and moisture reactions.

Landfill is the conventional disposal method in the world, and it is 10 times more likely to contribute to climate change and human toxicity than acidification, eutrophication, and incineration (Gao et al. 2017; Lee et al. 2007). In US, Landfill produces a significant amount of methane gas with 25-fold more powerful effects on climate change than carbon dioxide $CO_2$ (Hall et al. 2009). According to a research report, during the years of the reported period, only food surplus grew from 310 to 510 kcal/cap/day. This increase causes an increase of > 300% in emission of GHGs from 130 to 530 Mt $CO_2$eq/year. The total food requirement has been estimated to be between 2 and 20% by 2050 which can cause 1.9–2.5 Gt $CO_2$eq/year (Hiç et al. 2016). The amount of FW and loss during the period 1961–2011 grew by a factor of 3 (540 Mt to 1.6 Gt). The emission of GHGs accordingly increased from 680 Mt to 2.2 Gt $CO_2$eq (Porter et al. 2016). Most of the waste was generated in developing economies largely from fruit and vegetable items. In order to meet an increasing food demand, there is a run to establish a number of food factories and to industrialize the food sector, which compromises a long-term global inequality (Weis 2013).

The environmental impact of food wastage mainly come from upstream food supply chain processes and poor management. Large amounts of GHGs, global warming potential (GWP) (Amicarelli et al. 2021), acidifying potential (AP), and eutrophication potential (EP) (Scherhaufer et al. 2018), ozone depletion potential (ODP) (Mu et al. 2017), photochemical ozone formation (POF) (Fei et al. 2021), abiotic depletion potential (ADP) (Al-Rumaihi et al. 2020), energy use (EU), human toxicity potential (HTP), water use (WU) (Kibler et al. 2018), human health (HH) (Duret et al. 2019) and land use (LU) (Usubiaga et al. 2018) are commonly derived from food waste.

In Europe, emissions-related food waste assess at 15.7% GWP, 15.1% AP, and 15.2% EP, wherein meat products contributing the highest contribution to the overall food waste impact (Scherhaufer et al. 2018). Food production and agriculture effect on natural resources, particularly water and energy, in US, the average energy required of food waste is around 300 million barrels of fuel per year and consumes 1/4 of the freshwater. The consumption of fresh water and energy during FW processing, directly impact global warming (Hall et al. 2009).

In Turkey, the footprints of carbon, water, and energy related food waste show that the energy-related food loss equals 8% of total national energy consumption per year; while the water disposal from only food loss estimated double the amount of the total national water consumed from all of the country sectors, and (GHG) has formed about 4% of national emissions generated from food wastage (Cakar et al. 2020).

Composting food waste has the greatest benefits to the environment than landfills or other disposal ways that apply for managing organic waste. Furthermore, composting is an alternative soil amendment that enhances the quality of the soil by reducing land-use change compared to peat (combusted plant matter extracted from wetland) (Saer et al. 2013).

In Qatar, windrow composting and anaerobic digestion (AD) combined composting, as the two common techniques for composting food waste, have been compared to estimate their negative impacts on the environment. Windrow composting has the greatest negative impact than anaerobic digestion combined composting in the GWP and acidification categories, while AD combined composting has the greatest impact on the human toxicity impact category (Al-Rumaihi et al. 2020).

Anaerobic digestion is another treatment method of recycling food waste. Comparing anaerobic digestion to landfilling, anaerobic digestion produces less adverse effects than landfilling on all environmental impact categories (Tonini et al. 2018). However, digestate fertilizer could be an interesting and better option than chemical fertilizer if some of the recommended and potential improvements in digestate are considered, such as minimizing emissions from anaerobic digestion by using green energy instead of fossil fuels and lowering the temperature and pH of the digestate to prevent microbial activity (Chiew et al. 2015).

Valorisation food waste to biofuel or bio-based chemicals is eco-friendly treatment. In Sweden, food waste can convert into biogas, succinic acid (SA), and corn to SA with maintain its low the environmental adverse impacts and could be considered an emerging bioeconomy (Brunklaus et al. 2018).

Animal feeding is preferable option among different choices of food waste treatment techniques for minimising food wastevolume and providing environmental and health benefits. However, it is still unlawful in the EU countries to give food waste to animals owing to lack of public support and the high cost of reintroducing it (Salemdeeb et al. 2017).

In general, the negative environmental impacts of FW are still more and need serious attention to be minimized through certain techniques.

In contrast, FW prevention in different food service sectors has a positive impact on the environment. In Europe, 13 case studies have been assessed the environmental benefits and impacts categories particularly, climate change and biodiversity of FW prevention in five subsectors care, hotels, restaurants, business and education canteens in Switzerland and Germany. For each meal, it is equivalent to 238 g of $CO_2$. Approximately 10% of the total avoidable FW and 9% is due to biodiversity-related effects. Climate and biodiversity impacts may be reduced by 58% and 37%, respectively, if FW reduction scenario is adopted. Over 70% of the FW's consequences on the environment and human health have been mitigated (Beretta and Hellweg 2019).

The environmental impact estimations are a useful tool for food stakeholders to compare and identify gaps and hotspots in food waste management.

## 5 Strategies to Curb Food Loss/Waste

Although a range of treatment techniques are applied across the globe for food waste management, such as recycling, landfilling, incineration etc., however, they have certain obstacle due to mishandling and mismanagement. Besides, continuously increased food production and agriculture is further worsening the situation. In context of this situation, new innovations along with existing food waste management technologies to address key challenges of food waste collection and proper disposal. Here, we will shed light on some of the strategies and recommendations to avoid food waste disaster.

### *5.1 Zero Hunger Hero Strategy*

FAO (2017) provides nine tips and practices that are encouraging less food waste and better people awareness about food reduction strategies and targeting Zero Hunger Hero. These nine practices aim to achieve food sustainability as given in Fig. 2. The strategy forces individuals to eat small portions of food at home and start diet to preserve your health, leave nothing behind or create a new dish from your leftover foods. Judicious and calculated shopping of items and their arrangement in the fridge on the basis of first in, first out. Set up a compost bin for food waste and send it to the closer farm or garden to be used for farming. The highly recommended practice is to donate the surplus food to the people who cannot afford to buy (FAO 2017; Science


**Fig. 2** Zero hunger hero tips and practices

2021). Practicing the steps outlined above are extremely helpful to save food. A social campaign will help in this regard to motivate individual at any level to adopt these steps. To achieve the SDG concerning food loss and waste, needs considerations and policy from various angles including at the retail level (Cakar 2022).

## 5.2 *Sustainable Food Loss/Waste Management*

There are several challenges preventing effective food waste management, for instance, a lack of consumer awareness, inflexible commercial policies at the store level, suppliers who do not care about promoting environmental initiatives and employees who do not get enough training on things like food rotation. It is imperative that sustainable management techniques be implemented in order to decrease food waste more efficiently (Filimonau and Gherbin 2017).

A wide range of approaches to generating sustainable food waste management will be addressed in this section.

Food waste and its consequences are best addressed by reducing FW at the source, since the vast majority of waste is created during food preparation and collection, regardless of how it is processed. There are suggested methods used in order to reach sustainable food loss/waste management (Dilkes-Hoffman et al. 2018; Gao et al. 2017). As examples, the composting under aerobic condition and in-sink food waste processors unit (FWP) that grind and shredder FW, are the preferable food waste reduction options at home since they have the least environmental impact at low cost (Lundie and Peters 2005). In US, FWP has been utilised as an alternative option to landfills since 1927 (Iacovidou et al. 2012).

Establishing a comprehensive management system is a successful management has been proposed for FWM. It is an integrating education, motivation, and command-control techniques including regulations and stakeholders to obtain appropriate policies. For instance, Taiwan is the ideal example of comprehensive waste management and as result of this system increases recycling activities of the country to about 2,100 tons of FW per day, with annual revenue of about TWD 2.7 billion. An integrated management system is deadly recommended for sustainable FW management particularly, in developing countries (Thi et al. 2015). Moreover, it requires scientists from many sectors to collaborate to develop ideal methods and concepts more environment friendly, with utilise the least energy and water used, the least waste produced, and low cost (Morone et al. 2019).

Adopting the food energy water nexus (FEW nexus) in the context of FWM is an example for integrated comprehensive sustainable management. FEW impacts management framework takes into account the impact of food waste as well as the subsequent management of food waste and post-disposal. It requires reducing the production of food waste and estimating the management of unavoidable food loss and waste. Also, it should be a wide range of ways and actors from both government and individual levels to work as a team. It's important to understand that food waste affects FEW in many ways by modelling the whole system, establishing feedback loops between food waste production and FEW consequences, and investigating connections between awareness and individual behaviour. These all data is needed to make a fair judgement of the process (Kibler et al. 2018).

Utilizing the network activity system such as Corporate Social Responsibility (CSR) is another type of management strategies to improve the transparency between organizations' activities and community and to integrate social and environmental fears in their commerce. Donation, institutionalization, and food waste reduction examples of CSR have been proven their efficiency in food controlling to achieve food security and contribute sustainable consumption and production (SDG 12). In addition, it leads to increase the quality of donated food, support fresh and healthy food for society and reach to a great number of needy people (SDG 2, 3 and 1). Furthermore, CSR can involve different organizations and companies in food waste recycling (SDG 16) (Moggi et al. 2018).

Also, enhancing public education to raise awareness and the knowledge among the population and engage the locals in the system that reduce food waste. For example, create new green alternative products that help to have a better value for the end-user with adopting a new distribution activity to embrace both the producers and consumers in the food production and distribution network for well understanding of the social concerns (Al-Obadi et al. 2022).

Innovative management practices can help achieve sustainable management and reduce food waste. Incremental and radical innovation are some of the types of inventive practices that the food industry applies in its management. Incremental innovation is the gradual improvement of the system, integrating processes and activities related to waste minimization with the latest technology. For instance, the green restaurant includes a green diet and equipment to attain zero-waste restaurants, doggy bags practice that encourages the customers to take their dining leftovers, and online applications platforms for food donations and end-of-day sales (Martin-Rios et al. 2018). In addition, food preservation or frozen food is additional example for incremental practice. In Austria, Fresh food waste accounts for 9.3%, while frozen food waste accounts for 1.6%. Generally, the total of food waste derived from fresh foods is 5.8 times greater than that of frozen foods (Martindale and Schiebel 2017). While radical innovation requires a lot of fresh knowledge and expertise, and it will take a lot of time, money, and effort for people to come up with novel solutions to the issue of food waste. For example, the waste generated by paper and pulp mills is converted into power using this technology (Martin-Rios et al. 2018). Likewise, Smart Garbage System, SGS is an Internet of Things (IoT) as a part of this approach which would achieve the highest levels of for organic waste management besides to minimizing the economic and environmental adverse impacts of FW production and supporting the circular economy concept (Abdullah et al. 2022; Hong et al. 2014).

Prioritize food waste prevention based on the environmental waste hierarchy that can be used to achieve sustainable food waste management (Cristóbal et al. 2018). Prevention of food waste becomes the preferable choice, followed by redistribution to needy people since they have low environmental impact with high cost-effective than others, then to animal feeding then, Anaerobic digestion and composting are becoming more popular ways to deal with food waste followed by thermal treatments with energy recovery and land spreading where it is used with plant-based products for agricultural purposes. Incineration and landfilling are becoming at the last management option, and they must be avoided based on their environmental impact and lack of positive outcomes (Garcia-Garcia et al. 2015).

Categorization food waste is critical to discovering the best strategy to manage and dispose of FW in an environment friendly manner. Food waste can be classified into categories based on nine phases or criteria: edibility, state, origin, complexity, animal product, stage of the supply chain, treatment, packaging, packaging biodegradable. Efficient framework must be developed for each of these criteria. Consideration is given to the positive and negative impacts, as well as the environmental, economic, and social ramifications of each criteria (Garcia-Garcia et al. 2015, 2017).

Power consumption, process efficiency, disposal costs, and emissions all contribute to the cost of improving food waste management systems in a sustainable manner (Lee et al. 2007).

### 5.2.1 Value Added Products

Most strategies that have been used in food waste management focus on minimizing food waste rather than valorising the waste as a good and sustainable alternative solution. Value added products can be derived from food waste valorisation such as biofertilizers, biofuel, composting, polymers etc. (Fig. 3). Biofertilizers can be improved soil health, other value added products can also be used to retain water worth to be used in arid regions of the world to increase food production, and bioenergy can be utilised to reduce our dependence on fossil fuels (Morone et al. 2019). Fats, proteins, and bioethanol can be extracted from plant-based waste by using available technologies (Garcia-Garcia et al. 2015). Biofuel and bioproducts might decrease greenhouse gas emissions from landfills and preserve natural resources like coal and fossil fuels, therefore FW could offer environmental, social, and economic benefits (Girotto et al. 2015). High-tech strategies including thermal and biological waste treatment technologies are proposed for sustainable management since they are both cost-effective and environmentally benign. Thermal treatment, which contains hydrothermal carbonization, ethanol production and fermentation. Biological treatment that includes anaerobic digestion, mechanical–biological treatment and composting (Ananno et al. 2021).

Anaerobic digestion is type of sustainable management method for dealing with food waste since it is inexpensive, creates minimal waste, and transforms food waste into a sustainable source of power generation, solid fuel, and heat recovery (Fig. 3). It needs enzymatic hydrolysis, acid formation, and gas production (methanogenesis) with a set of microorganisms to produce bio-based products and maintain balance and stability of anaerobic digestion (Paritosh et al. 2017).

For example, Insect bioconversion can produce manure and dried larvae that is an interesting option in terms of covering the demand of feed production by using dried

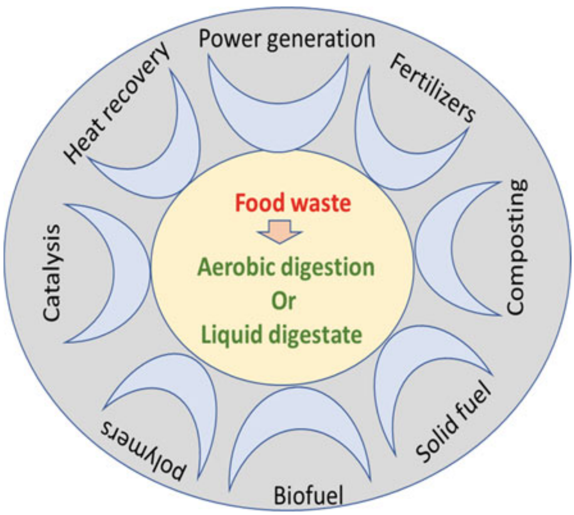


**Fig. 3** Value added products obtained from food waste management

larvae in aquaculture feedings. For instance, biotransformation of Black Soldier Fly Larvae (BSFL) namely, *Hermetia illucens*, can produce 300 kg of dry larvae and 3346 kg of compost from 10 tons of discarded food. BSFL reduces organic waste weight by 50% in a faster time than conventional composting. Also, insect-based product is rich resource for biodiesel production and organic fertilizer which lead to decline in GHGs. Generally, the BSFL organic waste treatment system is a green technology and sustainable (Amrul et al. 2022; Salomone et al. 2017).

Damaged ecosystems and habitats may be repaired using microorganisms and the enzymes as part of a bioremediation technique. For example, pesticides, herbicides, insecticides, cleaning chemicals may convert them into less toxic substances to be absorbed into organisms and environment due to apply bioremediation techniques. Fruits and vegetables, olive oil, fermentation, dairy products, meat, and poultry are all ideal uses for bioremediation in the food industry. Bioremediation is an effective method for dealing with environmental pollution caused by waste from food industry (Thassitou and Arvanitoyannis 2001).

The FWM should be a comprehensive strategy that takes into consideration social constructionism, intellectual concerns, and organisational aims and policy plans in addition to management (Martin-Rios et al. 2018).

### *5.3 Legislations and Laws*

Managing food waste is one of the wide world greatest challenges. The four R's: Reduce, Reuse, Recycle, and Recover is used as an indicator for waste hierarchy in reducing and managing food waste. To improve food waste reduction should integrate the multi-parties to cooperate in waste management strategies and implementations, involving governments' authorities, private industrial companies, households, and changing individual and culture waste disposal practices (Al Qahtani et al. 2021).

In Japan, the food recycling Law was enacted in 2001 according to this law, manufacturers and emitters are encouraged to turn food waste into compost or animal feed as well as biogas or heat from incineration. Competition from synthetic fertilisers, worries over safety and a low demand for recycled materials have made it difficult for recycled compost to gain attention. As a consequence, in 2007 the Law was revised to emphasise the significance of food recycling named (Loop Recycling) which permits recycling facilities to collect and transport food waste across municipal borders with requirements of purchasing farm products that use food waste-derived products, such as compost and animal feed to complete the loop (Takata et al. 2012).

Under the new law, more food waste is collected and recycled, with high environmentally beneficial and less expensive. Dry-feeding and bio-gasification procedures have lower GWPs because commercial feed and electricity have a significant influence on $CO_2$ emissions. It is possible for animal feed facilities to vary greatly in their usage of energy, food waste moisture contents and recycled materials while drying food (Takata et al. 2012).

In the USA, there are several legislations and strategies in different states for limiting landfills disposal of food waste, for example, California, Connecticut, Massachusetts, Vermont, Portland, San Francisco, Seattle, and New York. The laws emphasise source segregations and implement organic recycling programs for businesses, institutes, and residences which are food waste generators (Hodge et al. 2016).

In Korean government, has series of strict laws, for example, sorting food waste at source and implement volume-based charge system, generation gradually decreased from 1998. In 2005, landfills were banned which accounted for more than 90% of wasted food, and it replaced by recycling system (Lee et al. 2007).

Moreover, there are some countries such as Brazil, Turkey, Malaysia, Mexico, Costa Rica, Romania, South Africa, Belarus and Chin who have passed adequate laws with a timeline to achieve sustainable FW management. In Brazil, it aimed to end all open dumps by 2014 and to separate and collect 36% of recyclable waste and 53% of organic waste by 2030. In Turkey, the operation of composting and power generation facilities using methane gas is mandated by law to reduce the amount of landfill of FW (Thi et al. 2015).

Comprehensive FWM policies or programmes have not yet been put in place, in many countries throughout the globe. In KSA, food waste recycling has begun, however only a tiny fraction of the country's food waste is produced by informal activities. Saudi Arabia's Eastern Province has set up food waste recycling programme to encourage individuals to cook fewer meals, thereby reducing food waste. Laws are still lacking, landfilling is prevalent, public views are negative, and there is a lot of ambiguity especially public acceptability of FW's value-added products. Saudi Arabia's annual MSW and FW outputs might climb to 6.7 million tonnes by 2032 if no additional stringent FWM regulations or laws are implemented (Mu'azu et al. 2019).

In Bangladesh, there have not policy or law to shift municipal solid waste (MSW) management system. Organic waste is not yet separated from other waste or mixed with municipal rubbish. The MSW management still following the conventional formal system landfilling, is managed by municipalities. Besides, a community initiative that relies on the community to voluntarily dispose of its own waste, and an informal system that uses informal labour to dispose of waste (Ananno et al. 2021).

## *5.4 Circular Bioeconomy Approach*

Circular economy and bioeconomy ideas are being incorporated into economic activities. According to Circular Economy Action Plan, circular economy is conservation the value of the products or raw material in the economy for a long period throughout utilizing waste hierarchy, which includes sharing, reusing, redistributing, and recycling to produce secondary products with decreased waste and $CO_2$ (EuropeanCommission 2015; Mak et al. 2020). The bioeconomy is the generation of renewable biological resources with converting them into value-added products such as food, animal feeding, bio-based products and bioenergy.

Food waste conversion link bioeconomy with circular economy by ending up the food waste in organic waste recycling, energy, recovery or landfill disposal. Consequently, circular bioeconomy (CBE) could be the overlap of the concepts of a circular economy and bioeconomy, which aimed in improving resources to be efficient and environmentally friendly. They concepts are focussed on reducing greenhouse gases (GHGs) footprint and fossil carbon demands and valorising waste streams. Circular bioeconomy concept shares the same targets, which are enhancing the efficiency of resource utilization and valorisation waste materials, decreasing the gaseous emissions of during manufacturing and extraction processes (Mak et al. 2020). For example, food waste (eggshell and fly ash) can be utilized for industrial use to remove cadmium from wastewater. The materials used in the design are low cost, reusable, mass-usable, eco-friendly and have high performance (Segneanu et al. 2022).

A sustainable circular bioeconomy based on biomass may help tackle a variety of global environmental issues such as climate change, population expansion, limited natural resources and a rising need for food and materials. So far, the renewable energy directives didn't specify how biomass may be utilised to generate electricity or any other kind of power. It may be difficult to obtain energy back because of present constraints and economic decarbonization, which involves transitioning from fossil fuels to biomass (Mak et al. 2020).

The transition from the liner economy to the new concept circular bioeconomy concept to have closed loop of the FWM, and it requires the use of efficient technologies in a cost-effective and environmentally friendly design.

The Kingdom of Saudi Arabia (KSA) and the Gulf Countries (GCC) are following the linear economy concepts in their food waste management. For example, in Makkah city, the wasted food may increase to 1.60 million tons by 2030 due to the population growth, pilgrims to perform religious rituals, and practice the business-as-usual scenario (landfill site). If implement circular economy by bioprocessing recycling management (composting) in Makkah city, it would generate 0.23–0.40 million tons of compost with net revenue of 240–419 million Saudi Riyal (SAR), and a potential replacement of 124–216 kt of chemical fertilizers with savings will be 74–129 million SAR during 2015–2030. Also, implementing compost technology saving may be 618–1078 million SAR from the landfill and carbon related crediting, and reduce 0.043–0.076 million tons of Methane (CH4) emissions with net revenue of 1626 million SAR to the national economy of KSA in 2030. This proposed scenario would help the decision-makers establishing a suitable sustainable food waste management (Rashid and Shahzad 2021).

## 6 Steps to Be Taken for Sustainable FW Management

Here are some of recommendations which can help to manage FW in a judicious way:

To encourage research and innovations in the field of food waste management and cooperation with universities, research centres and institutions to evaluate the actual and potential quantities, expends and revenues of FW to make adequate decision for handling FWM and increase stakeholder's contributions in the field. Increase the public awareness and, in this case, it is important to use social media and television to educate individuals on how to plan and manage purchases. Food waste and loss control strategies, policies, and measures should be formed and prioritized to analyse the influence on the economic, nutritional and environmental cost along the food supply chain and water, energy and food security nexus and to be prepared for future unforeseen scenarios. Government in general should adopt a new approach such as reversal approach that focuses on sources reduction as first stage and landfilling as last stage in food waste treatment. Additionally, they should implement a policy for sorting and segregation FW at source for cost saving on collection, labour, transportation, and land value. Initiate and introduce fees and charges policy for FW generators to encourage food waste reduction practices and support different FWM services. Investors should utilize organic waste that estimates 40% of solid waste in Saudi Arabia to produce energy which helps to establish budget allocation for FWM and to meet circular economy concept. Encourage the mobilization of regional and global efforts through cooperative initiatives. For example, the collaboration among the GCC countries in this regard could help GCC countries to contribute corrective actions and measures to prevent FLW. The differentiation of the food wastage terminologies and classifications should be internationally unified to strengthen the food waste management and prevention in the globe.

## 7 Conclusion

Although food production is continually demand, its waste should adequately be managed to avoid the negative environmental and economic impacts. To achieve this goal, governmental and nongovernmental organization should adopt comprehensive sustainable approach, and they both must work together to ensure future sustainability and reduce the effects of the waste mismanagement. Also, it is essential to follow circular bioeconomy practice in food manufactories to support green economy and maintain the exist of natural resource for longer period. Moreover, they should establish a strong legislations and strategies along with raising public awareness for overcoming the burden gap in food waste management.

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# Chapter 11
# Food Loss and Waste in Saudi Arabia: Analysis, Causes, and Interventions

**Adam E. Ahmed and Fahad Alzahrani**

**Abstract** Food loss and waste (FLW) is a major concern globally due to its economic, environmental, and behavioral impacts. This chapter aims to analyze the FLW situation in Saudi Arabia for various food products and identify their main causes. It also highlights FLW hotspots along the food supply chain, economic and environmental impacts, and interventions to reduce FLW globally. The results indicate that about one-third of the food available for consumption in Saudi Arabia is wasted through FLW. The percentage of FLW varies between different products and stages of the food supply chain, including production, post-harvest, packing distribution, and consumption. In Saudi Arabia, FLW is particularly high for watermelon, tomato, unclassified fruits, vegetables, and meat, cucumber, zucchini, and potato. Additionally, FLW represents around one-third of flour and bread, rice, carrot, camel, and poultry products. The top five products lost in terms of volume are flour and bread, unclassified fruits, rice, poultry, and unclassified vegetables. The top five products lost in terms of value are unclassified meat, unclassified fruits, rice, unclassified vegetables, and flour-bread. The FLW percentage is highest for unclassified vegetables, watermelon, poultry, mango, and rice along the FSC stages of production, post-harvest, packing, distribution, and consumption, respectively. The chapter also highlights the causes of FLW in different food products and global interventions in the upstream, midstream, and downstream stages. In conclusion, there is an urgent need to raise awareness and implement legislation related to economic, legal, and behavioral dimensions to reduce FLW at all levels.

**Keywords** Awareness campaigns · Causes of food loss and waste · Food loss and waste · Food supply chain · Food loss · Food waste interventions

A. E. Ahmed (✉) · F. Alzahrani
Department of Agribusiness and Consumer Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: ayassin@kfu.edu.sa; adamelhag2002@yahoo.com

F. Alzahrani
e-mail: falzahrani@kfu.edu.sa

A. E. Ahmed
Department of Agricultural Economics, Faculty of Agriculture, University of Khartoum, Khartoum, Sudan



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## 1 Introduction

Producing an insufficient amount of food, coupled with a lack of necessary resources, presents a major challenge and concern for many regions and countries across the world. Despite this, almost one-third of food globally suitable for human consumption is lost due to food loss and waste (FLW) (Gustavsson et al. 2011; Pavone 2020; Leverenz 2021). In Saudi Arabia, the agricultural industry faces numerous obstacles in achieving sustainable food security and providing adequate nutrition for its population. These challenges include the country's harsh climatic conditions, limited arable land and water resources, and a high rate of food loss and waste caused by climate change (Baig et al. 2022). At a global level, food loss and waste equates to one-third of the world's food supply, totaling 1.3 billion metric tonnes. This represents production costs of one trillion USD, environmental costs of approximately 700 million USD, and social costs of around 900 million USD. To combat this economic problem, the Food and Agriculture Organization (FAO) has implemented an approach to reduce food loss and waste across the entire food supply chain, ensuring a sustainable food system to achieve food security and nutrition for all (SAGO 2019a). On average, FLW amounts to 45% of all fruits and vegetables, over 35% of fish and seafood products, around 30% of cereals and one-fifth of dairy, meat, and poultry (IFCO 2023). Numerous organizations, researchers, and studies suggest that approximately one-third of produced food is lost and wasted annually across the food supply chain, resulting in wasted resources such as labor, land, water, and capital, and having a significant environmental impact (FAO 2011).

Research and reports suggest that accurately estimating the extent of food loss and waste (FLW) on a global scale, especially in developing nations, can be challenging. Nevertheless, it is widely acknowledged that FLW is a significant issue. According to a survey conducted by the Food and Agriculture Organization (FAO), one-third of cereal production (30%), 40–50% of root crops, vegetables, and fruits, one-fifth of oil seeds, meat, and dairy products (20%), and over a third of fish production (35%) contributed to the total FLW. Various studies have identified numerous factors contributing to FLW, such as country-specific conditions and cultural, social, and economic circumstances (FAO 2015a).

In order to understand the nature and magnitude of the challenge related to Food Loss and Waste (FLW), it is crucial to clarify the differences between the various types of FLW. Currently, there is confusion surrounding the exact meaning of FLW due to the absence of a consistent definition, resulting in varying figures and values published by different agencies and researchers. According to a report from the FAO (2011), FLW encompasses the unused edible portions of plants and animals. This means that FLW causes a reduction in the amount of food available for human consumption, including both the overall mass of the food as well as the nutritional value and calorie content throughout the food supply chain (FAO 2019). FLW (food loss and waste) refers to the loss and waste of food products along the supply chain. This begins from the moment when food products are ready for harvesting on the farm, animals are ready for slaughter and milk extraction, farmed fish mature in ponds, and wild fish are caught in nets, and it ends with the consumption of these food products by people. FLW does not include the loss of agricultural and animal products during their growth stages (as defined by FAO 2011). Any food that is primarily intended for human consumption and has been removed from the food chain is considered food loss and waste, regardless of whether it is used for animal feed as fodder or to produce bioenergy (Mäkelä 2023). According to the FAO (2011) report, food that is removed from the FSC (food supply chain) may likely go to various destinations, including animal feed and fertilizer, landfill, unharvested crops, aerobic digestion, and biochemical processing. FLW does not include inedible by-products like bones, seeds, and peels, surplus food that is re-consumed by people through food banks, products produced for animal feed, seed production, or industrial production, and overuse or consumption in excess of the recommended caloric intake per person, as determined by FAO (2011).

According to the Food and Agriculture Organization (FAO) (2013), food wastage can be divided into two concepts: food loss and waste. Food loss refers to a decrease in the mass and/or quality of food meant for human consumption throughout the food supply chain, while food waste indicates the disposal of food that is still suitable for human consumption but is not consumed before its expiration date or is left to spoil (Reynolds et al. 2020). In addition, the FAO includes both food loss and waste under the concept of food wastage. In 2017, the FAO described food waste as any food that is thrown away despite still being edible. This could include leaving food in the refrigerator for too long and not consuming it in time (UN 2023), throwing away large portions of food that were served but not eaten, or disposing of leftover food that is still suitable for human consumption.

The European Union's "Food Use for Social Innovation by Optimising Waste Prevention Strategies (FUSIONS)" project has defined food waste as any food, including inedible parts, which has been discarded and removed from the food supply chain (FSC). This waste can be used for various purposes such as fertilizers, crops, digestion, bioenergy, incineration, and waste disposal. It can also be thrown away into the sewers, landfill, or sea. In contrast, the High-Level Panel of Experts distinguishes between food loss and waste. Food loss refers to the decrease in the mass of food throughout the supply chain before reaching the consumer level. On the other hand, food waste is the disposal of food suitable for human consumption or leaving it to spoil by the consumer, regardless of the reasons (HLPE 2014; UNDP 2021).

The United States Department of Agriculture defines food waste as a subset of food loss. Food waste occurs when edible food that is suitable for human consumption is thrown away (Buzby et al. 2014). Bellù (2017) further defines food waste as the act of disposing of suitable, raw, semi-processed, or manufactured food materials from the FSC due to spoilage, expiration dates, or consumer negligence. Other researchers distinguish food loss as the quantities of food lost by producers or during distribution, while food waste pertains to quantities lost at the consumer level (de Gorter 2014). Food wastage occurs on two levels: food loss denotes any damage or loss occurring to food from producers to wholesaler, whereas food waste relates to food loss at retailers' and consumers' levels (Gustavsson et al. 2011; Yildirim et al. 2016).

Due to factors such as the scarcity of natural resources and water, climate change, population growth, and rising food prices causing an increase in food insecurity, reducing food loss and waste has become a matter of concern for policymakers, international organizations, domestic institutions striving for food security, academic institutions, and researchers of various specializations (Gupta 2022).

The world is focusing more than ever on reducing food loss and waste, and as part of the United Nations' sustainable development goals (FAO 2019), the implementation of SDG-12—the second target—seeks to reduce FLW by half by 2030. This global commitment highlights the importance of reducing FLW, which occurs between farm and fork in the FSC (Sheahan and Barrett 2017). By reducing FLW, we can achieve the SDGs by 2030, contribute to the Paris Agreement on climate change, and ensure sustainable food production for the world's population by 2030. Sustainable development goal 12—"sustainable consumption and production patterns"—also plays a crucial role in achieving several other SDGs related to hunger, poverty, health, and greenhouse gas emissions (Alshabanat et al. 2021). The reduction in greenhouse gas emissions is a result of increased food use efficiency and reduced agricultural area and fertilizer use, which in turn has reduced emissions from food waste landfills (Searchinger et al. 2018; Willett et al. 2019). This highlights the opportunity to work on reducing food loss and waste, as well as the risks associated with climate change, sustainability of food systems, population growth, and human livelihoods along the FSC (UN 2023). The FAO and the UN Environment Program (UNEP) are making efforts to measure progress toward SDG 12.3 through two separate indices—the Food Loss Index (FLI) and the Food Waste Index (FWI) led by the FAO and the UNEP respectively (FAO 2019, 2023). Reducing food waste will contribute to improving the availability and accessibility of food without the need for additional agricultural production inputs, natural resources, and improved technologies. However, there have been few success stories in reducing food waste (WRAP 2009) and food loss (World Bank 2011), and inconsistent data and numbers related to FLW quantities still exist. This chapter aims to analyze the FLW situation in Saudi Arabia for various food products, identify the main causes of FLW, and highlight the FLW hotspots along the FSC for different food products. It also addresses the economic and environmental impacts of FLW and the interventions that have been proposed and adopted globally to reduce it.

## 2 Food Loss and Waste Across Regions

Several studies have indicated that the world is facing significant levels of food loss and waste. Food losses near the farm are predominant in low-income regions, while food waste near the plate prevails in high-income regions (Flanagan et al. 2019). According to FAO (2011), there is a global difference in the amounts of FLW along the FSC and according to region. Hotspots for food waste in high-income regions are at the consumption stage of household and restaurant levels, while in low-income areas, food loss on the farm and during post-harvest processes such as handling and storage is the hotspot. As for micronutrient losses caused by food loss and waste, food losses from vegetables and fruits are a hotspot near the farm in the regions of Asia, Africa, and sub-Saharan Africa. Loss of root and tuber crops represents a hotspot in the production stage and during the handling and storage stages of the FSC in sub-Saharan Africa. Evaluating calorie losses caused by food loss and waste, cereals represent a hotspot in Europe and North America during the consumption stage and a hotspot in Asia during the production, handling, and storage stages of the food supply chain. On the other hand, the loss of roots and tubers represents a hot point in the stages of production, handling, and storage in sub-Saharan Africa. Lastly, FLW contributes in varying proportions to greenhouse gas emissions. Beef, dairy, and rice production represent the hotspots for greenhouse gas emissions resulting from food loss and waste.

According to Table 1, the total food loss and waste (FLW) ranges from 26 to 36% of the total food supply. The region with the lowest FLW is South and Southeast Asia with 26%, while the highest FLW is found in North Africa, West and Central Asia, and Sub-Saharan Africa with 36%. At the production stage, Sub-Saharan Africa has the highest FLW at 12.96%, followed by Europe, Latin America, North Africa, West, and Central Asia with about 11%. During the handling and storage stage, Sub-Saharan Africa experienced about 13% FLW, while North America and Oceania had only 2.1%, and Europe had 3%. The regions with the highest percentage of food loss were Sub-Saharan Africa (12.96%), South and Southeast Asia (8.58%), Latin America (7.82%), and North Africa, West, and Central Asia (7.2%). These losses could be due to poor handling and storage facilities. Conversely, food loss during handling and storage amounted to only 2.1% and 3.4% in North America and Oceania, and Europe, respectively. The highest food loss percentages during the processing process were recorded in North Africa, West, and Central Asia (3.24%), and Latin America (3.06%), while it ranged between 0.67 and 2.58% in the other regions mentioned. On the other hand, high food waste percentages were reported in North America and Oceania (20%), Europe (14%), and Industrialized Asia (12%) at the consumption stage of the Food Supply Chain (FSC). Sub-Saharan Africa has the lowest food waste percentage at the consumption stage.

## 3 Underlying Causes of Food Loss and Waste Along the Food Supply Chain

This section discusses the causes of food loss and waste at different stages of the food supply chain. It is important to note that certain causes can affect multiple stages of the supply chain and even the overall food supply chain (FAO 2019). A supply chain refers to a network of connected individuals, organizations, resources, activities, and technologies involved in the production and sale of a product or service (Sharmistha 2022). Essentially, it includes all the steps taken by organizations from obtaining raw materials from suppliers to delivering the final product or service

**Table 1** Distribution of food loss and waste (FLW) throughout the food supply chain and across regions (%)

| | Production | Handling and storage | Processing | Distribution and marketing | Consumption | Total FLW (%) |
|---|---|---|---|---|---|---|
| North America and oceanic | 7.35 | 2.1 | 2.1 | 3.15 | 20.3 | 35 |
| Europe | 11.22 | 3.4 | 1.7 | 3.4 | 14.28 | 34 |
| Industrialized Asia | 9.86 | 6.8 | 0.68 | 5.1 | 11.9 | 34 |
| North Africa, West, and Central Asia | 10.44 | 7.2 | 3.24 | 6.84 | 8.64 | 36 |
| Latine America | 11.22 | 7.82 | 3.06 | 5.44 | 6.46 | 34 |
| South and Southeast Asia | 8.32 | 8.58 | 0.78 | 5.46 | 2.86 | 26 |
| Sub-Saharan Africa | 12.96 | 12.96 | 2.52 | 5.76 | 1.8 | 36 |

*Source* Compiled by the author from that data obtained from Flanagan et al. (2019)

to the end consumer. The term "supply chain" refers to an integrated system of processes, people, and organizations that are involved in moving something from its initial production location to the end consumer (Lutkevich 2023). Each product or service has its own distinct supply chain, but, in general, supply chains consist of raw material providers, producers, distributors, wholesalers, retailers, and final consumers. These participants carry out various operations like storage, processing, transportation, packaging, and handling.

When analyzing the agricultural food supply chain, we are referring to all the activities that create value by converting raw materials into finished products. The main objective is to connect farmers with the market and, on a larger scale, the global agricultural industry (Son et al. 2016). The International Fund for Agricultural Development states that small farmers play a crucial role in the global food industry. They not only contribute to employment in rural development and other sectors of the economy but also help create a market for services and products by increasing their income (Najera 2017). The agricultural supply chain has several crucial functions, including production, harvesting, storage, handling, and distribution. Production decisions involve tasks such as cultivating land and crops, and meeting cultivation requirements. Harvesting decisions involve determining the timing of the harvest, allocating resources, organizing labor and equipment, selecting transportation methods, and deciding packaging methods. In the storage phase, decisions revolve around monitoring crop stocks, establishing procedures for handling food stocks, determining storage and selling quantities, and considering storage needs during distribution. The distribution phase involves moving products through the supply chain until they reach the final consumer, which involves selecting transportation methods, organizing shipping, and ensuring timely delivery. Throughout all these functions and stages, producers face uncertainty, especially with perishable crops. Therefore, it is crucial to design management models for each crop that consider harvest policies, marketing channels, logistical activities, vertical coordination, and risk management (Ahmuada and Rene 2010).

Throughout the world, there are various factors that contribute to the loss and waste of food during production and after harvesting. Some of these factors include inadequate harvesting practices. For instance, if the harvest is done at an unsuitable time or there is improper handling during transportation, the use of inappropriate machinery and equipment for the products can also lead to losses. Additionally, poor storage facilities and inefficient transportation infrastructure worsen the problem. Climate change further exacerbates the situation by causing unfavorable conditions like droughts, floods, and storms that result in the loss of food products. Pests and diseases also significantly contribute to the loss of food during production and after harvesting. FLW refers to the removal of food that is appropriate for human consumption at various stages of the food supply chain (FSC), spanning from food production to consumption. The FSC is defined as a "connected sequence of activities used to produce, process, distribute, and consume food" (Colwill et al. 2016; FAO 2019). The removal of edible food from the FSC can be directly attributed to multiple reasons, such as the deterioration of food safety and quality, the lack of demand or market for food products, and the unsuitability of food products for human consumption. These underlying reasons may be related to issues such as low-quality food, unacceptable appearance, an abundant food supply that surpasses demand, and fluctuations in seasonal food production (Flanagan et al. 2019). Furthermore, the occurrence of these basic reasons for removing edible food from the FSC chain can be attributed to four underlying drivers: technological, administrative, behavioral, and structural, as illustrated in Fig. 1 summarizes the food loss and waste underlying drivers.

## 3.1 *Causes of Food Loss and Waste at Upstream, Midstream, and Downstream*

In this section, the causes of food loss and waste at various stages along the food supply chain will be discussed. These stages are broken down into three main categories, each with its own subcategories. The first stage is the upstream stage, which includes production and post-harvest processes. The second stage is the midstream Stage, which involves processing and distribution. Finally, the third stage is the downstream stage, which pertains to consumption.

Numerous researchers have identified various reasons and causes that contribute to food loss in the production and post-harvest stage (upstream stage). Some of these include prevailing climatic conditions such as high temperature, rain, storms, and floods (UN 2023), as well as weather variability. Additionally, inaccessibility

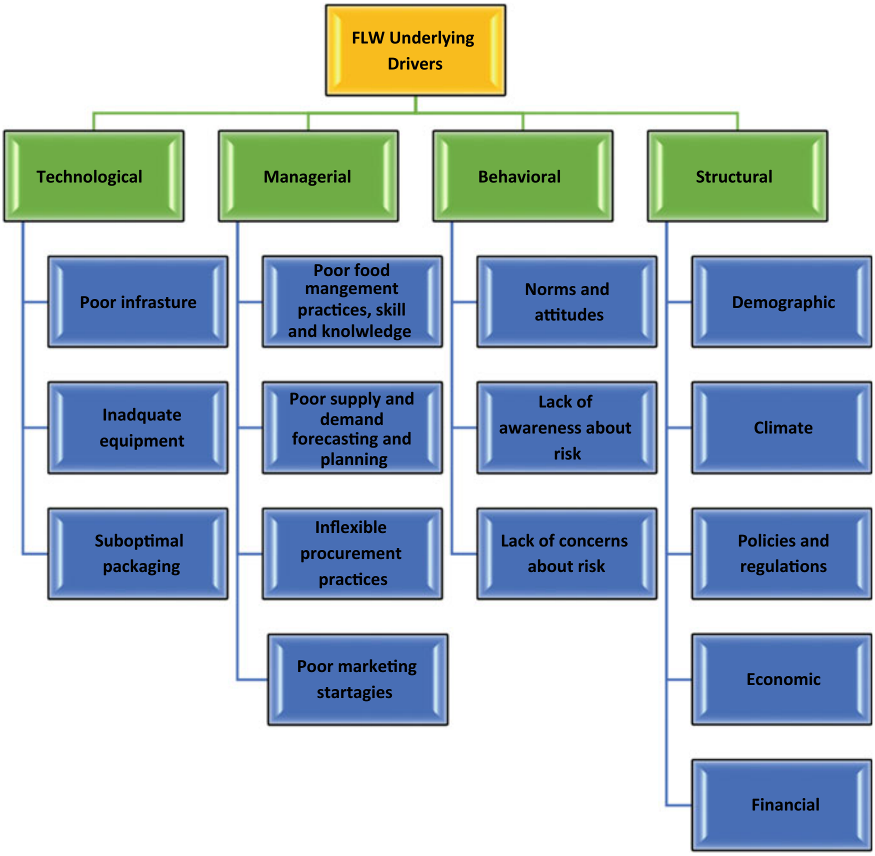


**Fig. 1** The underlying drivers of food loss and waste. *Sources* Developed by the author based on the classification of Flanagan et al. (2019)

to timely and reliable weather data (Flanagan et al. 2019; Beausang et al. 2017; Mena et al. 2014; Nahman and de Lange 2013; Gadde and Amani 2016), improper harvesting times (UN 2023), inappropriate harvesting equipment (Flanagan et al. 2019), poor harvesting and post-harvesting practices (UN 2023; SAGO 2019b); premature harvesting, mechanical damage and spillage during harvest operations (FAO 2011), marketing constraints (UN 2023), suboptimal or deterioration of food product quality due to pests, diseases (Flanagan et al. 2019), animal death and sickness (Mena et al. 2014; Corrado et al. 2017; Beausang et al. 2017; FAO 2011), inadequate and poor infrastructure, insufficient training to reduce food loss (Flanagan et al. 2019), lack of efficient and well-trained manpower, distance between production and consumption areas (SAGO 2019b), seasonality in food production and price fluctuations (Gadde and Amani 2016; Plazzotta et al. 2017); non-compliance of food products with retailer requirements and specifications (Priefer et al. 2016; de Steur et al. 2016; Calvo-porral et al. 2017; Richter and Bokelmann 2016), overproduction, inadequate demand forecasting, and excessive stock (Magalhães et al. 2019a, b; Priefer et al. 2016; Calvo-porral et al. 2017; Richter and Bokelmann 2016; Plazzotta et al. 2017; Nahman and de Lange 2013; de Lange and Nahman 2015).

Researchers stated that there are many factors responsible for food loss during the processing and distribution (Midstream stage). These factors include poor, improper, and inefficient infrastructure (UN 2023; SAGO 2019b; Priefer et al. 2016), inefficient food trade logistics (UN 2023), improper/inadequate handling practices (UN 2023; Priefer et al. 2016; Mena et al. 2014; de Steur et al. 2016; UN 2023), lack/insufficient handling best practices training, poor handling practices during loading and unloading (Flanagan et al. 2019), displaying food products on the roads (SAGO 2019b; Flanagan et al. 2019), unavailability of alternative markets, lack/insufficiency of environmentally friendly cold storage facilities, poor coordination and lack of information, weak marketing strategies, non-compliance with the specifications of food products, slaughterhouse conditions (SAGO 2019b), and spillage and degradation during handling (FAO 2011).

There are multiple and interconnected causes for food loss during the storage stage. For instance, storage conditions play a crucial role in food waste. If food products are stored in unfavorable conditions such as high temperature, cold, or humidity, it can spoil the food and reduce its quality. It is important to note that improper packaging can result in damage and contamination of food products during transportation and storage. Additionally, pests, particularly those found in stores, significantly contribute to food spoilage. Moreover, mishandling of food products during storage, storing large quantities of food in one place without proper ventilation, and a lack of regular inventory control and poor management are also reasons for food loss during the storage phase. In this context, researchers have identified different causes of food loss and waste during the storage stage, which include: inadequate, improper, and poor storage facilities (Flanagan et al. 2019; SAGO 2019b); spillage and degradation during handling, storage, and transportation from farm to distribution (FAO 2011; Parfitt et al. 2010; Kowalska 2017); improper storage and selling conditions in wholesale and retail facilities (FAO 2011); short shelf-life duration (UN 2023; Mena et al. 2014); storage facilities located far from the farm; adoption of high-cost storage and handling technologies; insufficient initiatives with beneficiaries (Flanagan et al. 2019); lack of refrigeration and sterilization centers for vegetables and fruits (SAGO 2019b); and climatic factors (SAGO 2019b).

Furthermore, during processing, handling, and packing, researchers have identified additional various causes of food loss. These include improper processing and packaging facilities (UN 2023), Poor packaging methods, Low-quality packaging materials, Insufficient and malfunctioning processing facilities (UN 2023), Inappropriate product size leading to increased food loss and waste, inefficient processing methods, spillage and degradation during industrial or domestic processing (FAO 2011).

At the retail level, there are multiple factors that contribute to the loss and waste of food. These factors encompass the short duration of shelf-life (Magalhães et al. 2019a, b), the presence of unattractive and misshaped food items that fail to meet aesthetic standards regarding color, shape, and size (UN 2023), low demand for specific food products, the existence of expired food items, and the adoption of strict quality appearance standards by major supermarkets, which results in food being discarded (Stuart 2009). Additionally, insufficient market systems also play a role in this issue.

Food loss and waste at the downstream level (consumption) is caused by various factors. These include poor home storage facilities (UN 2023), excessive purchasing, lack of proper meal planning, labeling problems, large package sizes, and the practice of preparing excessive amounts of food for hospitality and special occasions. Another significant factors is the lack of awareness and public education in schools and other sectors, which affects people's attitudes toward food waste (SAGO 2019b) and encourages behaviors such as bragging and extravagance. Non-compliance with food product specifications and consumer behavior also contribute to food waste, along with the abundant production of food commodities (UN 2023). At the restaurant level, causes of food loss and waste include plate waste in the front office and issues related to storing and preparation in the back office.

### *3.2 Food Wastage Footprint and Climate Change*

In terms of food security, statistics show that globally, one out of every nine people suffers from malnutrition. However, despite this, over one billion metric tons of food are lost or wasted every year (FAO 2018). It is estimated that approximately one-third of the food produced globally is lost or wasted, resulting in economic, environmental, and social costs (Spang et al. 2019). According to the FAO (2017a, 2017b), global food waste amounts to an estimated 1.6 billion metric tons annually, of which 1.3 billion metric tons are edible and have a market value of USD 750 billion. However, to feed the global population of 9.3 billion people, food production needs to increase by 50–70% (Meacham et al. 2013; Yildirim et al. 2016). Food loss and waste contribute to the climate crisis as they are responsible for global greenhouse gas emissions (GHGs). The food supply chain is a significant contributor to GHG emissions, exacerbating climate instability and leading to severe weather events such as droughts and floods. This, in turn, affects food crop productivity and quality, increases food waste, and ultimately threatens food security and nutrition. Food production and land use change also result in greenhouse gas emissions (FAO 2019). The carbon footprint of food wastage is estimated at 3.3 $GtCO_2e$, making it the third largest source of GHG emissions after the United States and China. Similarly, the blue water footprint of food wastage is estimated to be 250 $km^3$ annually from surface and groundwater. Food wastage also accounts for a loss of approximately 30% of arable land globally, which equates to 1.4 billion ha, and has negative effects on many sectors, including biodiversity (FAO 2013). This has led to the widespread publication of information regarding FLW (Spang et al. 2014). About a quarter of land, water, and fertilizers used in food production are wasted due to food wastage, which may exacerbate the situation for food production worldwide due to limited natural resources and environmental constraints (Shafiee-Jood and Cai 2016; Yildirim et al. 2016). Addressing the problem of FLW leads to a triple win because it reduces costs for farmers and companies, allows for the feeding of a larger number of people using the same resources, and reduces pressure on climate, water, and land (Flanagan et al. 2019). The impact of FLW is significant, affecting various areas like the environment, economy, food security, jobs, and ethics. Food wastage contributes about 8% of greenhouse gases emitted annually, consumes 25% of the water used in agriculture, and requires an area of agricultural land estimated at about 9.6 billion km$^2$ (FAO 2015b). As a result, food supply chains must be more sustainable by reducing the current levels of food loss and waste.

The researchers stated that reducing food loss and waste (FLW) by 50% by 2050 would result in several economic, environmental, and social benefits. For instance, it would save more than one-fifth of the food deficit between 2010 and 2050, eliminate the need to convert an area of 2.8 million km$^2$ into agricultural land between 2010 and 2050, and reduce greenhouse gas emissions by 1.5 gigatonnes of $CO_2$ equivalent per year by 2050 (Searchinger et al. 2018).

## 4 Food Loss and Waste Reduction Interventions: International Experiences

The Food and Agriculture Organization of the United Nations has created and introduced numerous initiatives, studies, and expert recommendations and advice to decrease food loss and waste globally. This is with the goal of aiding in achieving global food security and sustainable development objectives (SDGs) while also preserving the sustainability of productive resources. One among the numerous recommendations and pieces of advice provided by FAO's experts includes nine tips to decrease food waste, according to a study they conducted in 2017.

1. The individual should order a small portion of food for each meal and may take more if necessary.
2. Edible leftovers should not be thrown away but can be stored properly for later use.
3. To practice smart shopping, one should buy only what is needed, prepare a shopping list, avoid excessive shopping, and refrain from food shopping when hungry.
4. Purchasing unattractive and irregularly shaped fruits and vegetables, as their nutritional value is not dependent on their appearance and can help reduce food waste.
5. Properly preserving and storing various types of food in different locations, including the refrigerator, by following the product's specific storage instructions.
6. Adhering to the "first in, first out" rule when arranging food in storage and the refrigerator. This involves organizing products with longer shelf lives towards the back, while placing those with shorter shelf lives in front for prompt consumption.

7. It is important to understand the dates on your food. Once the "use-by" date has passed, the food should not be consumed as it is no longer safe to eat. However, "best-before" dates indicate the quality of the food in terms of its smell, texture, and taste. If stored properly, most non-perishable foods can still be consumed after their "best-before" date.
8. If food waste is inevitable, it should be converted into compost. A compost bin should be created for this purpose, in which food waste can be placed and used as fertilizer instead of being thrown into the regular waste bin, which contributes to greenhouse gas emissions.
9. Surplus food should be donated to reduce food waste. The surplus food should be given to the needy, ensuring its safety and quality for human use. It is important to note that there are many associations, restaurants, shops, and civil society organizations that collect, prepare, and distribute surplus food to the needy to reduce food waste and help those in need of food.

In the following section, we will provide examples of interventions taken by various actors, including governments, industries, and non-governmental organizations, to combat food loss and waste (FLW) globally. The European Parliament Council (2008) states that any intervention aimed at addressing FLW should follow the food-waste hierarchy depicted in Fig. 2. This hierarchy prioritizes solutions to FLW into five levels. The first priority is to avoid FLW by addressing the causes and sources of the problem. The second priority is to repurpose surplus food for human consumption. The third priority is to recycle food into compost or animal feed. Finally, energy recovery and waste disposal are the least preferred options and should be considered as a last resort.

The degree of food loss varies depending on the stage of the food supply chain. This variability is due to several factors including the type of crops, level of economic development, and social and cultural customs in the region (Rezaei and Liu 2017). Developing countries generally incur losses during the production and

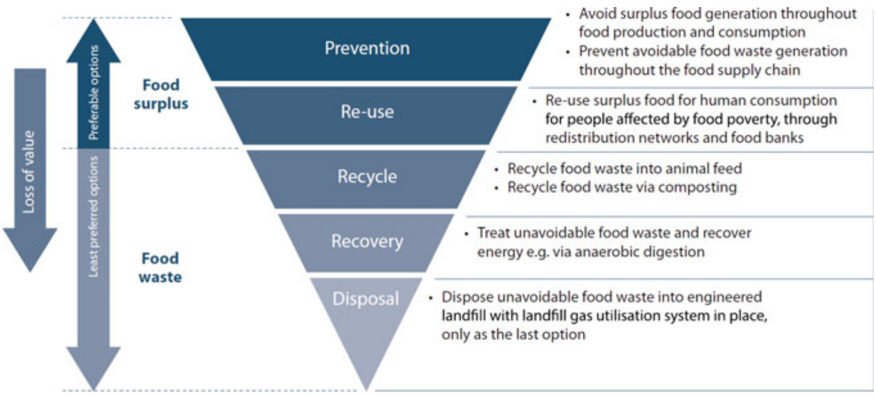


**Fig. 2** Hierarchy of solutions to food loss and waste. *Source* Adopted from UNEP DTU Partnership (2021)

post-harvest stages (upstream stage), while developed countries experience losses during the consumption stage (downstream stage) (Lipinski et al. 2013a, b). To mitigate food loss and waste, various instruments such as public policy and regulation, taxes and fees, voluntary agreements, information dissemination, nudging, and standards are available, which can be used at different stages of the food supply chain. Depending on the context and objective, interventions are categorized into three aspects-implementation level, actors involved and affected by the implementation, and the type of intervention (Table 2). The micro-level interventions aim at solving problems related to a single stage of the food supply chain, such as an initiative targeted at enhancing the storage of farm products to reduce food loss. Meso-level interventions affect multiple stages of the food supply chain. For example, workshops and educational programs designed to teach groups of farmers proper post-harvest practices, conducted by local extension officers. Macro-level interventions are implemented by the local or national government and can have a far-reaching effect. For example, initiatives like expanding the network of paved roads or offering tax incentives for specific technologies. These interventions can have an impact on the entire food supply chain, a region or group of actors, and are usually implemented by the government.

In general, policies and initiatives related to food loss and waste can be classified into three main objectives: (a) to improve food security and nutrition, (b) to promote environmental sustainability, and (c) to enable business growth (FAO 2019). We will analyze various interventions carried out by different actors and categorize them based on the three main supply stages of the food chain: upstream, midstream, and downstream.

**Table 2** Food loss and waste interventions categories

| Level | Actors | Type |
|---|---|---|
| Micro | Farmers (smallholders) | Technology |
| Meso | Governments | Finance and investment |
| Macro | Educational programs | Good practices |
| | Facilitators | Organization |
| | Innovators | Policy |
| | Intermediaries | Economics |
| | Retailers | |
| | Financiers | |
| | Researchers | |
| | Civil society | |
| | Processors and manufacturers | |
| | Packaging providers | |

*Source* Adopted from Soethoudt et al. (2021)

## *4.1 Interventions at the Upstream Stage (Production and Post-harvest)*

According to the Food and Agriculture Organization (FAO) report of 2011, approximately one-third of the food produced globally in 2009 was lost or wasted. Nearly half of this quantity (48%) was lost during the production and post-harvest processes, as stated by Lipinski et al. (2013a, b). The loss of food during these stages is due to various administrative and technical limitations prevailing in harvesting, storage, transportation, processing, cooling facilities, packaging, and marketing systems in developing nations. By enhancing these initial stages of the food supply chain, it could lead to significant strides towards achieving food security, such as increased production and reduced food commodity prices throughout the distribution network. Furthermore, such improvements would have a positive impact on the environmental sustainability of food systems, as it would lower the pressure on natural resources such as land and water (FAO 2019). The food supply chain (FSC) facilitates these improvements by providing technical interventions in the early phases, as noted by Soethoudt et al. (2021).

### 4.1.1 Crates for Tomatoes in Nigeria

According to FAOSTAT (2021), Nigeria is one of the leading producers of tomatoes worldwide. However, more than half of the locally produced tomatoes go to waste, as stated by Ugonna et al. (2015). In 2018, Wageningen University & Research, Agrofair, N-N-Solutions, and the International Fertilizer Development Center (IFCD) collaborated on an initiative aimed at testing and introducing a new packaging method for tomatoes. This intervention was designed to reduce waste in both the southern and northern regions of the country. Instead of the traditional raffia baskets used by farmers, they used returnable plastic crates to transport the tomatoes. These stackable crates provided greater stability, reducing the risk of mechanical damage to the tomatoes during handling and transportation. The intervention successfully reduced food loss and quality decay. The use of crates resulted in a weight loss of 5–12% less than that of baskets and significantly lower loss of A-grade quality tomatoes—between 2 and 15% compared to baskets at 27–37%. This intervention highlights the potential for technology to make a significant impact in reducing food waste.

### 4.1.2 Improving On-Farm Storage

By providing farmers with efficient, secure, and accessible storage options for their crops, post-harvest losses can be reduced through improved storage practices. Various initiatives exist that aim to enhance post-harvest storage, such as the AgResults Kenya On-Farm Storage Challenge Project (Tanager 2018). In this initiative, nine private companies competed for performance-based grants totaling $7.75 million, which were awarded to those who sold grain storage devices to smallholder farmers in Kenya's Rift Valley and Eastern regions (the country's largest maize-producing areas). The winner was determined by their sales numbers and required to provide technically proficient and inexpensive grain storage devices. The program ran from 2014 to 2018 and included four storage types: storage-enhancing bags, storage-enhancing flexible bulk bags, plastic containers, and metal containers. Over the three-year period, participating companies sold 1.4 million improved storage devices, resulting in an improved storage capacity of 0.41 million metric tons for households. This shielded farmers from 12 to 20% of food losses. Other interventions aimed at improving storage include micro-warehousing and grain trading platforms in Western Kenya (Bingham 2020), Nestle's preservation systems in Kenya (Nestle Global 2023), the UN World Food Program in Uganda and Burkina Faso (Costa 2014), and the U.S. Department of Agriculture's farm storage facility loan program (USDA 2023b).

#### 4.1.3 Finding New Markets for Second-Grade Products

Agricultural products that are considered ugly, misshapen, or damaged do not meet industry cosmetic standards and are often not sold through intended channels. These products are typically repurposed as animal feed or processed into alternative products, like juice, or may not leave the farm or warehouse at all. A study conducted in the Flemish region of Belgium in 2017 surveyed 300 farmers and found that 66% were unable to sell a portion of their products through intended sales channels due to their failure to meet cosmetic quality standards (Roels and Van Gijseghem 2017). On average, these farmers lost approximately 10% of sales. Furthermore, over half of all misshapen products did not make it through the human food chain, resulting in food losses. Efforts to reduce such losses are prevalent in the United States and Canada, where new markets and collaborations are helping to increase sales of second-grade products. Examples of such initiatives include online stores like Second Life and Naturally Imperfect in Canada and Imperfect Foods in the United States. Government policies are also playing a big role in enabling new sales channels for farmers. For instance, in 2016, the Quebec government abolished its previous regulations on fresh fruit and vegetables under the Food Act, which had previously banned the sale of products that did not meet cosmetic standards.

### *4.2 Interventions at the Midstream Stage (Processing and Distribution)*

In this stage, FLW represents approximately 16% of the total loss and waste in the world, according to Lipinski et al. (2013a, b). The majority of interventions at this stage concentrate on managing food waste that arises from retail, restaurants, and other food services. Examples of such interventions are reviewed in this section.

### 4.2.1 Food Donations and Date Labeling Laws

Regulations are, without a doubt, one of the most effective methods of dealing with Food Loss and Waste (FLW). An additional key solution to decreasing food waste is the redistribution of surplus food that is appropriate for human consumption. Certain governments have taken steps to address food waste from supermarkets and businesses by creating laws that either forbid the waste of food or encourage donations. For example, the French government passed the Supermarket Waste Ban Law in 2016, which prevents supermarkets from disposing of unsold food or rendering it inedible through the use of chemicals. Supermarkets that are larger than 400 $m^2$ are required to establish an agreement with one or more organizations, such as food banks, to redistribute their surplus or unsold food. Non-compliance with these regulations can result in fines of up to 75,000 euros. Italy likewise has several laws that address different aspects of reducing food waste. This includes a legislative decree in 1992 that deals with labeling, differentiating between the "expiration date" and the "best before date" of food products, two decrees in 2003 that pertain to donating food to charities, and the supermarket waste law introduced in 2015, which encourages donations (Blakeney 2019). Two laws in the United States aim to increase contributions to charities (USDA 2023b). The first is the Bill Emerson Good Samaritan Food Donation Act of 1996, in which every state has passed legislation limiting the liability of food donors who are held responsible for foodborne illnesses. The second is the Internal Revenue Code of 2011, which provides companies with higher tax deductions as an incentive to donate healthy and wholesome food to qualified non-profit organizations that serve underprivileged and impoverished individuals.

### 4.2.2 Discounting Aging Products

One way to address food waste at the retailer level is by lowering the price of products that are nearing their use-by date. This approach is widely used across the world, such as in Norway where over 90% of supermarkets have a separate area for selling short shelf-life food products at a discount of up to 50% (Capodistrias 2017). In 2020, an initiative was launched to help these stores advertise their discounts using a phone app called "Throw No More." In Spain and Italy, more innovative pricing technologies using machine learning have been used to help retailers reduce waste and increase revenue through dynamic pricing. Wasteless is one such technology that automatically discounts the prices of food products as their expiration date approaches, using electronic shelf labels. Testing this technology in a leading Spanish retailer and an Italian hypermarket resulted in an average reduction of 32% and 39%, respectively, in overall waste and an average revenue boost of 6% and 110%, respectively (Wasteless 2018, 2019).

#### 4.2.3 Smaller and More Durable Plates

Food waste in the hospitality and catering industry is mainly caused by spoilage, food preparation, and leftover food on consumers' plates. Often, food is prepared but not served, or served but not eaten. An effective intervention to reduce food waste in such cases is to change the size and/or type of plates served to customers. For example, a study conducted in Norway found that decreasing plate size resulted in a 19% reduction in food waste (Kallbekken and Sælen 2013). Similarly, in the US, reducing French fry portions led to a 31% reduction in food waste (Freedman and Brochado 2010). Another study in the US discovered that replacing disposable plates with permanent ones reduced food waste by 51% (Williamson et al. 2016).

### *4.3 Interventions at the Downstream Stage (Consumption)*

Approximately 35% of global food waste takes place during this particular stage, as noted by Lipinsky et al. (2013a, b). Given that household consumption is the primary culprit of food waste, numerous measures have been implemented to tackle this issue, as discussed by Reynolds et al. (2019). We will explore some of these interventions in this section.

#### 4.3.1 Information and Awareness Raising Campaigns

Information has been widely used to alter people's behavior. Interventions based on information aim to modify consumer awareness, knowledge, preferences, and skills regarding an issue. Information can be delivered through various means like awareness and social-norm campaigns, educational efforts, skill training, prompts, labelling, feedback, and self-commitment (UNEP DTU Partnership 2021). For instance, a non-profit organization called Stop Wasting Food in Denmark began spreading awareness and creating impactful campaigns in 2008, urging a significant change to reduce food waste at all stages of the food chain supply. With this organization leading the efforts between 2010 and 2015, Denmark witnessed a 25% reduction in food waste (Szulecka et al. 2019). Many comparable campaigns were also initiated in various countries, such as Stop Food Waste in Ireland, Save the Food in the US, Love Food Hate Waste in the UK, and Clean Your Plate in China.

#### 4.3.2 Food Waste Tax and Subsidies

Taxes and subsidies have the power to affect consumers' behavior through incentives. South Korea has implemented a unit-based food waste tax in stages between 2009 and 2015. This is also known as the "pay-as-you-throw food-waste recycling system." The tax amount is small, averaging at $0.06 per kilogram or $1.3 per household per month, based on the average amount of waste produced. The tax was collected via a smart card system or an official trash bag. The tax policy resulted in a 20% reduction in annual food waste, a 5.5% reduction in annual grocery purchases, and a 4.4% decrease in spending for the average household (Lee 2022). On the other hand, poorly planned subsidies can encourage food waste. The Egyptian government subsidized flour before 2014 in an attempt to create a social safety net and increase food security. However, both consumers and sellers engaged in wasteful behavior. Therefore, in 2014, the government reformed its bread subsidies program by providing subsidies on bread instead of flour, and restricting the number of loaves an individual can purchase each day through a smart card system. Following this reform, there was a 15–20% decrease in demand for bread (FAO 2019). Jordan implemented a similar approach in 2018.

#### 4.3.3 Tracking Food Expiration Date

Technology can provide us with easy solutions to the food waste crisis, particularly at the consumption stage. For instance, researchers from the UK and India have developed the nosh app that utilizes Artificial Intelligence (AI) to assist households in monitoring the contents of their fridge and pantry, offering advice on how to prepare and consume everything before the specified expiration dates. Another example found in the UK is smart food labeling; according to reports, the sell-by, use-by, and best before dates used for perishable products provide inadequate information to customers about the condition of the product on the shelf and its deterioration, causing a higher risk of health issues and increased waste. Mimica Touch is a new high-tech food label that becomes ‘bumpy’ when the food has expired.

## 5 Food Loss and Waste in Saudi Arabia

### *5.1 National Program for Reducing Food Loss and Waste (NPRFLW)*

The Vision 2030 and the National Transformation Program of the Kingdom of Saudi Arabia aim to make efficient use of natural resources and improve operational efficiency. To achieve one of its goals of working with consumers, food manufacturers, and traders to reduce waste, the Ministry of Environment, Water, and Agriculture (MEWA) has adopted the National Program for Reducing Food Loss and Waste (NPRFLW). This program is based on international standards, experiences, and good practices and includes a field survey covering all regions of the Kingdom. The initiative is being implemented by the General Food Security Authority (GFSA), formerly known as the Saudi Grain Organization. The NPRFLW aims to measure and quantify the amount of food loss and waste, analyze its causes, propose plans and policies to reduce it, and prepare a performance index for FLW in Saudi Arabia. The program focuses on two domains: FLW reduction and preparing the legislative framework for reducing FLW. Additionally, training will be provided to stakeholders in the private sector on best practices to reduce food loss and waste. The ultimate aim of these objectives is to enhance cooperation between stakeholders in the supply chain to improve food product reuse and promote the capacity for recycling food waste that is not suitable for human consumption.

The National Program for Reducing Food Loss and Waste (NPRFLW) is comprised of four phases. The first phase involves conducting a field survey to study FLW reduction in Saudi Arabia. The second phase involves preparing and implementing national awareness training programs to reduce food loss and waste. The third phase includes conducting a national observatory of FLW in Saudi Arabia. Finally, the fourth phase focuses on studying the capabilities of waste recycling and benefiting from food loss and waste. The first phase of the program has been completed, and as a result, the baseline FLW index for Saudi Arabia has been issued. Currently, work is underway on the second phase of the program (SAGO 2020).

FLW, which stands for Food Loss and Waste, is one of the most significant challenges facing the world at large, and the Kingdom of Saudi Arabia in particular. According to a report published by the Food and Agriculture Organization of the United Nations (FAO), an estimated 931 million tons of food were wasted in 2019. Meanwhile, a study by SAGO and the FLW Reduction Program in Saudi Arabia, conducted to determine the baseline measurement of the FLW index in the country, found that the food loss and waste rate had reached 33.1%, equivalent to 4.06 million metric tons. Finding ways to reduce food loss and waste is crucial in achieving food security, decreasing the negative impacts of food wastage, reducing food costs and increasing spending efficiency, as well as lessening the pressure on waste treatment systems (SAGO 2019a). On a per capita basis, the amount of food loss and waste is estimated at 184 kg/year, with loss accounting for 79 kg and food waste accounting for 105 kg/year. In Saudi Arabia, the total value of FLW is believed to be around 40 billion SAR per annum (SAGO 2019a). Of the total percentage of food loss and waste in Saudi Arabia (33.1%), the food loss rate is 14.2%, equivalent to 1.736 million tons, while food waste is 18.9%, equivalent to 2.33 million tons.

In the second phase, the awareness campaign aims to reduce food loss and waste (FLW) by producing media outputs that motivate community members to adopt effective behaviors in Saudi Arabia. The campaign has a set of strategic objectives, which include: (a) Raising awareness about the efficient use of natural resources in agriculture. (b) Increasing awareness of the importance of dietary diversity. (c) Encouraging the reduction of food loss and waste. (d) Raising awareness about the diseases that result from food waste and how to deal with food wastage. (e) Enhancing cooperation among government agencies, non-governmental organizations, restaurants, and retail stores, and (f) Promoting food reuse and recycling in Saudi Arabia.

The NPRFLW's second phase will occur in three stages, each consisting of two campaigns. The first stage aims to provide information about FLW from legal, economic, social, and environmental perspectives. This stage is divided into two campaigns. The first campaign targets merchants, restaurants, hotels, and hall owners, farmers, public markets, and other stakeholders. It lasts for two months. The second campaign lasts for four months and targets community members, including families, government agencies, and male and female students at all stages during the school year. If it coincides with vacations or other events, it will be delayed in coordination with SAGO. The third stage is the behavioral educational stage, which focuses on ways of raising cultural awareness to reduce losses and waste, and its positive impact on society. It also consists of two campaigns, starting 30 days after the second stage. The first four-month cultural and educational campaign targets a representative sample of families, government agencies, and students. It contains specific elements such as preparing an awareness booklet that is the nucleus of a school curriculum, modifying consumer behavior, illustrating the importance of purchasing necessary commodities according to their need, and rationalizing the amount of cooked and consumed food.

The second campaign is an educational and cultural program that lasts for two months. This program targets farms, factories, public markets, vegetable markets, food markets, and commercial establishments. The program aims to address the following aspects: (a) Preparing an educational guide for these groups that contains the most important means and optimal methods for dealing with food items throughout the supply chain. (b) Highlighting the best methods of handling food items throughout the supply chain. (c) Raising awareness of the risks associated with mismanagement of foodstuffs from legal, environmental, economic, and social perspectives, regardless of their quantity.

The SAGO and NPRFLW are excited to deliver the messages and goals of the awareness campaign to targeted government and private agencies, as well as the non-profit sector and volunteer teams within the community. These partnerships were established with relevant institutions, including 16 government agencies, 25 private sector entities, 13 conservation associations, and 13 volunteer teams, for a duration of 20 months. The NPRFLW community partnerships project has six main objectives: (1) To educate the participating entities about the importance of the national program aimed at reducing FLW. (2) To provide different sectors with the opportunity to participate in the program, with a focus on social responsibility. (3) To increase the level of engagement and interest from all stakeholder sectors. (4) To enable the program to reach community members more easily. (5) To reduce time and costs by leveraging facilities provided by different stakeholders in support of the awareness campaign, and (6) To gather ideas, opinions, and innovations from participating sectors to help effectively communicate the program's message.

The community partnerships are proposing tasks, duties, and programs that include sending awareness messages, preparing and presenting educational lectures and seminars, creating digital, traditional, and internal advertisements, hosting short lectures and digital events, designing creative interactive content like infographics and motion graphic videos, placing panels in dining halls and hospitality venues, forming teams of program friends, attending program meetings, attracting and training volunteer ambassadors for the awareness campaign, jointly publishing digital content on social media platforms and digital platforms of the main parties, publishing educational materials from the project's products on screens and corridors at the headquarters of participating agencies, and conducting capacity-building courses and seminars about the importance of food loss and waste reduction. Furthermore, several factors contribute to the success of the community partnership project, such as receiving official support from the project owner, having clear determinants, motives, incentives, roles, and responsibilities for the community partnership, and ensuring that the partners trust and consolidate their efforts.

### *5.2 Food Loss and Waste Baseline Study*

As part of the National Transformation Program, the former Saudi Grains Organization conducted a study to estimate and quantify the volume of food loss and waste (FLW) in Saudi Arabia. The study consisted of 41,790 samples distributed across 13 regions and 35 cities/governates in the country. It covered 19 food commodities, grouped into eight food categories (as illustrated in Fig. 3), and traced along 33 food supply chains using six scientific methods. The baseline survey found that one-third (33.1%) of food products are lost or wasted annually along the food supply chain (FSC) in Saudi Arabia, with this proportion further decomposing into food loss (14.2%) and food waste (18.9%). Additionally, the study found that the annual per capita FLW in Saudi Arabia is around 184 kg, according to reports by SAGO (2019a) and Alshabanat et al. (2021).

To identify the economic dimensions of food loss and waste (FLW) in Saudi Arabia, we will analyze the data released from the baseline loss and waste study in the following sections. The analysis will encompass the economic aspects of FLW for a range of basic products at various stages of the supply chain. We will identify the causes of loss and waste for each product, quantify the amounts and percentages of loss and waste during different stages of the supply chain, and make recommendations to reduce FLW during each stage.


**Fig. 3** Baseline study on food loss and waste: food groups. Author preparation from the data obtained from SAGO (2020)

### 5.2.1 Flour and Bread

The amount of lost and wasted flour and bread accounted for 30% of the total available quantities. Of this amount, 25% was due to food loss, while 5% was due to food waste. This resulted in a total loss and waste of wheat of approximately 917,000 tons, with a value equivalent to 913 million riyals. The survey also discovered that around 155,000 tons of flour and bread were lost during the distribution phase (including bakeries, supermarkets, and wholesale stores), while 762 thousand tons were wasted at the final consumption level (such as in homes or restaurants). On a per capita basis, the loss and waste amounted to approximately 28 kg/year (Table 3). In order to decrease the amount of loss and waste of flour and bread, SAGO (2019b) suggested a number of recommendations related to production, consumption, and waste reduction. For example, maintaining current production quantities was seen as important, as was increasing support for farmers to improve crop productivity (in accordance with international standards of 3 tons/ha). Developing an irrigation policy that prioritized productivity while also reducing water consumption was also suggested, as was improving the quality of wheat production and importation in order to raise the quality of flour and bread. Due to high levels of bread waste, major changes were suggested for the bread industry, including the mass production of high-quality national bread that met consumer needs and ensured food safety and security. Awareness and educational programs aimed at reducing consumption were also recommended, along with changes to bread production methods (such as producing smaller slices of bread instead of whole loaves, with greater attention paid to weight checks) and the development of mechanisms for reusing baked goods surplus as animal feed.

### 5.2.2 Rice

Rice is considered to be the most important crop that feeds humanity because it is consumed by half of the world's population. Saudi Arabia is one of the countries with highest rice consumption, with per capita consumption amounting to 48 kg per person per year. Annual rice imports in Saudi Arabia depend mainly on various types of rice, with about 1.5 million metric tonnes of rice imported in 2020/21, according to foreign trade statistics published by the General Authority for Statistics. This is an increase from 1.3 million metric tonnes imported in 2016, with a total value of 3.93 billion Saudi riyals. India is the main supplier of rice to Saudi Arabia, accounting for over two-thirds (70%) of the annual import needs. In 2016, Saudi Arabia re-exported about 11.8 thousand metric tonnes of imported rice to neighboring countries, with a total value of 40 million SAR according to SAGO (2019a, b).

The results of the baseline survey by FLW indicated that in Saudi Arabia, 3% of the total available quantity of rice is lost mainly during the distribution stage, such as transportation and storage, and 30.6% of the available quantity is wasted during the consumption stage. Therefore, in 2016, approximately 33.6% of the total rice available, amounting to 1,658,000 tons with a value of 1682.5 million SAR, were

**Table 3** Food loss and waste by product and along the food supply chain

| | FLW% | Food loss % | Food waste% | Volume (1000 mt) | Value (million SAR) | Production | Food supply chain | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Postharvest | Packing | Distribution | Consumption |
| Flour-bread | 30 | 5 | 25 | 917 | 913 | 0.03 | 0.01 | 0 | 17 | 83 |
| Rice | 34 | 3 | 31 | 557 | 1.682 | 0 | 0 | 0 | 9 | 91 |
| Dates | 21.5 | 16 | 5.5 | 137 | 588 | 18 | 24 | 0 | 31 | 27 |
| Mango | 26 | 17 | 9 | 12 | 42 | 0 | 0 | 4 | 50 | 46 |
| Watermelon | 41 | 32 | 9 | 153 | 254 | 26 | 28 | 0.32 | 24 | 22 |
| Orange | 28 | 14.5 | 13.5 | 69 | 181 | 0 | 0 | 2 | 27 | 71 |
| Unclassified fruits | 40 | 22.5 | 17.5 | 608 | 2257 | 45 | 0.6 | 0.1 | 10 | 44 |
| Tomato | 40 | 23 | 17 | 234 | 428 | 41 | 2 | 1 | 14 | 42 |
| Cucumber | 43 | 26 | 17 | 82 | 260 | 48.5 | 2.5 | 0 | 10 | 39 |
| Carrot | 31 | 16 | 15 | 27 | 47 | 33 | 2 | 2 | 16 | 47 |
| Zucchini | 41 | 26 | 15 | 38 | 74 | 49 | 2 | 0 | 11 | 38 |
| Potato | 42 | 28 | 14 | 201 | 372 | 44 | 2 | 1 | 11 | 42 |
| Onion | 26 | 8.5 | 17.5 | 110 | 167 | 15.5 | 1 | 0 | 17.5 | 66 |
| Unclassified vegetables | 44 | 27.5 | 16.5 | 335 | 1252 | 54 | 2 | 3 | 11 | 30 |
| Sheep | 15 | 7 | 8 | 22 | 401 | 12 | 15 | 3 | 17 | 53 |
| Camel | 34 | 14.5 | 19.5 | 13 | 150 | 23 | 22 | 2 | 15 | 38 |
| Unclassified meat | 43 | 24 | 19 | 41 | 619 | 8 | 20 | 4 | 20 | 48 |

(continued)

**Table 3** (continued)

| | FLW% | Food loss % | Food waste% | Volume (1000 mt) | Value (million SAR) | Production | Food supply chain | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Postharvest | Packing | Distribution | Consumption |
| Poultry | 29 | 13 | 16 | 444 | 2799 | 9.2 | 14 | 4.5 | 26 | 46 |
| Fish | 33 | 18.5 | 14.5 | 69 | 494 | 20 | 1 | 4 | 31 | 44 |

*Source* Complied by the author based on the data from SAGO (2019b) lost or wasted. Rice loss during the distribution stage accounted for 9% of the overall rice wastage in 2016, equal to 49.7 thousand tons. The remaining 91% of rice wastage occurred during the consumption stage, totaling over half a million metric tons of rice. Moreover, the per capita rice wastage annually was about 16.8 kg. Rice is the most frequently wasted food in the country, which highlights the need for collective efforts. The recommendations include implementing an integrated program to reduce rice wastage, which should include various measures such as raising awareness, motivation, imposing penalties, and prevention. The goal is to find practical solutions and awareness initiatives to promote rational consumption of rice and reduce the impact of Saudi Arabia's consumption habits on rice wastage, particularly during special occasions and weddings. Food can be recycled and reused, which should be regarded as a valuable benefit. Additionally, creating an initiative to encourage popular restaurants and wedding locations to reduce rice waste in their meals by providing tax benefits, financial and honorary incentives, and enforcing punishments for violators that do not adhere to the principle of preserving resources.

### 5.2.3 Dates

Since ancient times, palm cultivation has been considered one of the most important agricultural activities in Saudi Arabia. The palm tree is a source of goodness and blessing, and it provides year-round food for the residents of the region. The abundant cultivation of date palms is due to the suitability of the climate for tree growth requirements. The country's annual production of dates is estimated at over one million metric tons, with the central region contributing about 60% (616,000 metric tons), followed by the eastern region with 15.2% (163,500 metric tons), and the western region with 15.2% (157,000 metric tons). Saudi Arabia achieved self-sufficiency in dates at an estimated rate of 118% in 2021, which is a slight increase compared to 2016 (113.7%). In 2016, the amount of date production in Saudi Arabia was estimated at about 1000 thousand metric tons, but the quantity available for human consumption was estimated at 637,000 metric tons. This means that approximately 350,000 metric tons with a value of 587 million SAR are inadequate for human consumption and are wasted or used as animal feed (Alshabanat et al. 2021). At the early stages of the supply chain of production, post-harvest, handling, storage, and distribution, the percentage of date loss amounted to 15.6% of the available quantity, while the waste rate did not exceed 6%. There are numerous factors that cause date loss, such as rain in the spring during pollen season, the spread of pests like the red palm weevil, poor storage conditions, and traditional harvesting methods. Regarding the distribution stage, the loss of dates is mainly due to approved marketing strategies and the storage conditions in distribution places such as retail stores or even wholesale markets. The SAGO baseline study proposed several suggestions and recommendations to reduce the loss and waste of dates. These include: (a) Continuing scientific research to improve pest control and coordinating with entities such as the National Center for Palm and Dates and the Center for Palm and Date Research at King Faisal University. (b) Guiding palm farmers in the techniques of collecting, handling, and processing dates. (c) Disposing of infected date waste by converting it into organic fertilizer, animal fodder, and biofuel. d. Preserving the quality of dates. (e) Establishing more factories for packing, manufacturing, and creating new food products from date surplus, and (f) Developing new ways to reduce waste through improved labeling, inventory management, and storage facilities.

### 5.2.4 Fruits

The total amount of loss and waste in mangoes was 11.83 thousand metric tonnes, which represents 26.2% of the total amount of mangoes available for consumption. This amount of loss and waste is divided into two categories: a loss rate of 16.9% in the early stages of the mango supply chain and 9.4% of waste in the consumption stage. It is important to note that the distribution and consumption stages of the mango supply chain, which make up 50% and 46% of the chain, respectively, are the most critical stages where the highest amount of loss and waste is recorded.

In 2016, around 153,000 mt watermelon products were lost or wasted along the food supply chain in Saudi Arabia, which is half of the amount available for consumption. Approximately 40.3% of watermelon usable quantity is lost during the first four stages of the food supply chain, while only 8.9% of watermelon is wasted at the consumption stage. There are numerous causal factors for watermelon loss and waste, including harsh climatic factors, the use of traditional tools, poor seed quality, inadequate storage and distribution facilities, selling the product on the side of the road where it may be exposed to sunlight for prolonged periods, decreasing the quality of the product and subsequently increasing loss of the product. Saudi Arabia's climate features fertile soil that extends over vast areas, allowing the production of various types of fruits. Among the most important types of fruits produced in the Kingdom are muskmelon, which is grown in Tabuk, grapes grown in Medina, Taif, Qassim, and Al-Jouf, apricot, peach, and pear which are grown in Al-Jouf city. The total loss and waste rate for unclassified fruits is estimated at 39.9% of the amount of fruit suitable for consumption, where the loss rate in the first stages represents 22.4% of the available amount, while the percentage of waste in the last stage of the supply chain is 17.5%.

### 5.2.5 Vegetables

This section will analyze various vegetables, including potato, carrot, zucchini, tomato, and onion, as well as a group of unclassified vegetables. SAGO (2019b) reported that 27.8% of the total available quantity of potatoes is lost at various supply chain stages, and 14.1% of these quantities are wasted during consumption. As a result, 41.9% of the total quantity of potatoes available in the Kingdom in 2016, equivalent to 200.72 thousand tons, were lost due to loss or waste, valued at approximately 372.4 million SAR (see Fig. 4). It seems that the amount of lost potatoes during production is incredibly high, presenting a major problem that requires immediate action to enable farmers, especially small ones, to improve their crop collection methods using high-tech methods. Furthermore, practical solutions must be found to provide seasonal trained labor for potato production. On the other hand, 16.1% of the total available quantity of carrots is lost at various stages of the food supply chain, and 14.5% of these quantities are wasted during consumption. As a result, 30.6% of the available quantity of carrots in the Kingdom in 2016, equivalent to 87.6 thousand tons, were lost due to loss or waste, valued at approximately 46.8 million SAR (see Fig. 4). It is worth noting that carrots are lost during the production stage, either during pre-harvest or during crop collection. They may be left in the ground for numerous reasons, such as poor harvesting methods, delayed harvesting, and high harvesting costs. In a similar vein, out of the total quantity of cucumbers within the food supply chain, 15.4% of this quantity is wasted during consumption. The total amount of cucumber that is lost or wasted represents 25.8% of the total available quantity of cucumbers; approximately 16.7% of this quantity is wasted at the consumption stage. As a result, 42.5% of the total quantity of cucumbers available in the Kingdom in 2016, equivalent to 191.8 thousand tons, were lost due to loss or waste, valued at approximately 260 million SAR. The Saudi per capita share of the total lost and wasted quantity of cucumbers is only 2 kg/year. With regard to the onion crop, 8.4% of the total available quantity of onions in the Kingdom was lost at various stages of the supply chain, and 17.2% of these quantities are wasted during consumption. As a result, 25.6% of the total quantity of onions in the Kingdom in 2016, equivalent to 428 thousand tons, were lost due to loss or waste, valued at approximately 167 million SAR.

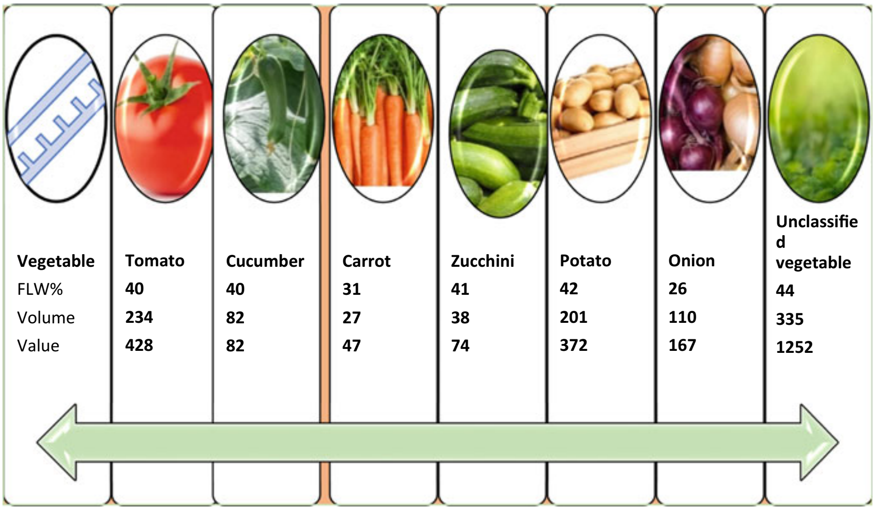


**Fig. 4** Vegetable loss and waste in KSA (volume in 1000 mt) and (value in million SAR)

In regards to the tomato harvest, 23.1% of the total available quantity of tomatoes were lost at different stages throughout the supply chain. Additionally, 16.5% of these quantities were wasted during the consumption stage, resulting in a total loss of 39.6% of the available tomato quantities in the Kingdom in 2016. This loss, including the waste, equated to approximately 589.7 thousand tons of tomatoes with a value of about 429 million SAR. Roughly 42% of the waste occurred at the end consumer level in homes or restaurants, totaling about 97.8 thousand tons of tomatoes. The remaining vegetable products that are not classified include eggplant, okra, pepper, cabbage, cauliflower, and various types of leafy greens. According to the statistical book of the Ministry of Environment, Water and Agriculture, these vegetables were grown on 10.8 thousand ha of land, of which 984 ha are under open cultivation. In 2017, the cultivated areas produced about 187 thousand mt of open vegetables and 69.7 thousand of protected vegetables (Fig. 4).

### 5.2.6 Red Meat

The production of red meat in Saudi Arabia has seen slow growth but also an improvement in standard of living and increase in per capita income, leading to an increase in local demand for red meat. This has resulted in the Kingdom importing a larger amount of red meat. Unfortunately, there is a significant amount of loss and waste in the red meat industry, with 31.3% of the total amount available for consumption being wasted. The main stages of loss are storage and distribution, which account for 19% and 18% of total loss and waste, respectively. Consumer habits also contribute to the wastage of red meat, accounting for approximately 48% of the total loss and waste. The study found that health factors during production and storage conditions in slaughterhouses and supermarkets, as well as the lack of efficient labor force, are among the major causes of loss and waste in the red meat sector. Sheep wastage, on the other hand, accounts for 14.5% of the total quantity available for consumption, with distribution and storage methods being the primary causes of loss and waste, accounting for 17% and 15% of the total, respectively. Additionally, 12% of sheep wastage occurs on farms, and inefficiency in labor force as well as climatic and health factors contribute to the loss and waste of sheep meat. Consumption behavior of individuals is also a significant factor that leads to the loss and waste of sheep meat, accounting for 53% of the total.

The amount of camel meat lost or wasted was 34.2% of the total quantity available for consumption. The largest portions of this loss occur during production and distribution, both accounting for 23% and 22%, respectively. During the production process, many camels are lost due to factors such as weather and disease. Storage conditions, marketing strategies, and distribution methods are also significant factors in the loss of camel meat. Additionally, 38% of this loss is attributed to individual consumption behaviors. Similarly, the loss of beef meat totals 43.1% of the total quantity available for consumption. Of this loss, 20% each is lost during distribution and storage phases. Factors such as inefficient slaughterhouse and supermarket practices, poor storage conditions, late delivery, and exposure to disease and weather contribute to the loss of significant amounts of beef. Individual consumption behavior also plays a significant role in excessive waste, accounting for 48% of total beef loss.

### 5.2.7 Poultry

The poultry sector experiences a loss and waste of 29.1% of available poultry for consumption. The primary reasons for this situation include the method of distribution, storage conditions, and production processes. These factors account for 26%, 14%, and 10% of total loss and waste, respectively. Additionally, individuals' consumption behavior contributes to almost half (46%) of the total loss and waste of poultry. The baseline study shows that health-related concerns, such as the spread of viruses and bird diseases, non-conformity of products to required specifications, and inefficiency of the labor force, are significant causes of loss and waste in the poultry sector.

### 5.2.8 Fish

The quantity of fish that is lost or wasted accounts for 33% of the total amount of fish available for consumption. It has been observed that the major reason for this loss and waste of fish, up to 51% of the total, is due to wastage in both production chains (20%) and distribution chains (31%). Additionally, the consumption behaviour of individuals contributes to a waste of 14.5% of the fish meant for consumption. The outcomes of the field survey establish that the traditional fishing methods, non-adherence of the product to the required specifications, and the distribution methods between major markets are among the primary causes of fish loss and waste.

## 6 Conclusion and Prospects

Food loss and waste (FLW) is a global issue because it has severe effects on the economy, society, and the environment, resulting in the squandering of scarce resources. In Saudi Arabia specifically, FLW accounts for 33.1%, including loss at 14.2% and waste at 18.9%. This is considered a high percentage globally because it represents one-third of the food available for consumption in Saudi Arabia, totaling over four million metric tons of food and valued at approximately 12 billion USD annually. Reducing FLW should be the responsibility of all individuals and institutions, including government and non-government entities, the private sector, and UN agencies. Each institution has a role to play across the food supply chain (FSC) stages of production, post-harvest, packing, distribution, and consumption to diminish FLW and achieve the targeted reduction of 50% by 2030, as per the MDGS targets. Determining the sources and root causes of FLW across the FSC is the first step towards designing programs, proposing initiatives, and adopting technologies to reduce FLW.

Institutions and community segments can contribute to this by increasing awareness campaigns to inform individuals about the impact of FLW and how they can diminish it, developing ways of recycling food surpluses, and creating policies and strategies geared towards FLW reduction.

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# Chapter 12
# Food Security Early Warning Systems in Saudi Arabia

**Shamseddin Musa Ahmed**

**Abstract** Escalated climate risks and calamities due to global warming and climate variability made, long before then, the adoption of an early warning system (EWS) a basic human right, which enables individuals, communities, governments, and organizations to take adaptive measures in due time to save souls, infrastructure, economic assets, and among others. Despite that EWS is axiomatic and long-standing, however, it is yet moseying, especially its application in food security which is the pith of human development. The role of EWS in mitigating the hasty rate of disasters related to food insecurity has fetched global attention nowadays, bearing in mind the strong ushering of the United Nations to increase the adoption rate of EWS up to the last mile in the next few years. This chapter synopsis how EWS could contribute to food security; it also delimits the main components of EWS models, with a special reference to food security; gaps and opportunities to increase the effectiveness of food security EWS models were also analyzed. Results showed that diversified EWS models exist, but with no a wide consensus on its basic components, and food security ones made no exception. In which, risk knowledge, monitoring and forecasting, dissemination and communication, and response remain the generally-agreed components. Lack of a clear objective, data scarcity, inadequate analysis, and uncertainty in forecasting. dissemination of information persisted poor participation of citizens, and lacking of integration remained yet the central challenges facing the effectiveness of the established food security EWS. Advanced technologies (e.g. remote sensing, Geographical information system, artificial intelligence, cloud data storage, and social media) have the potential to fill these overburden gaps. The regional successful experience in the application of FSEWS is summarized. Raised concerns on climate change and sustainability imposed the compelling need to revisit the vogue food security definition "*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*

S. M. Ahmed (✉)
WMII, University of Gezira, Wad Madani, Sudan
e-mail: Shamseddin@uofg.edu.sd

Visiting Researcher, Institute of Research and Consulting, King Faisal University, Al-Ahsa, Saudi Arabia



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*active and healthy life*"; the author suggests that any sustainable and working definition of food security EWS should empower four pillars: food supply, sustainability intensification, economic prosperity, and quality of life, which is exemplified in the Kingdom of Saudi Arabia. The institutionalization of a reliable food security EWS is an adaptive process, depending on sharing experience, lessons learned, participation, and partnerships at global, regional, national, and local levels.

**Keywords** Food security · Global warming · Sustainability · Early warning system models · Kingdom of Saudi Arabia

# 1 Introduction

Ancients have defined four basic needs for every human being: water, food, shelter, and clothing. The so balanced environment has been used to maintain these vital human needs. Mankind, however, failed to keep pace between development and the environment. Rapid population growth, excessive urban encroachment into fertile lands, massive deforestation, pollution of readily freshwater resources, and excessive emission of anthropogenic greenhouse gases (GHG), among others, have spurred several real environmental challenges.

Figure 1 surmises a potential relationship between the increasing trend in concentrations of GHG and population growth, viz. the unsustainable anthropogenic activities of human beings are in control for 100 ppm of carbon dioxide concentrations in the last 60 years, from 316.91 to 416.45 ppm. The tangible result is the current global warming (Fig. 2), attested by the 1.1 °C increase in surface air temperature above the mean of the eighteenth century. This has substantially disturbed the normal climatic patterns that humans and ecosystems did somehow adapt to, ultimately disquieting human activities, including food production, livelihood generation, human health, social, and cultural ones (Inter-governmental Panel on Climate Change, IPCC 2022). For instance, rainfed agriculture (permanent and seasonal crops) has used to sustain more than 60% of the food production worldwide (de Souza et al. 2021); however, rainfed agriculture is a high precipitation pattern-dependent food system; for that reason, any negative anomalies in precipitation would have serious impacts on the rainfed crop yields which might trigger a vicious cycle of poverty and food insecurity, hatching a large number of immigration waves from rural areas and civil unrest (Affoh et al. 2022; Jaramillo et al. 2020; Shamseddin 2022). Figure 3 presents anomalies in global precipitation since the year 1900, ranging between a reduction of 49 mm $yr^{-1}$ and an increase of 98 mm $yr^{-1}$; this states also the intrinsic spatiotemporal variability in precipitation, which has driven frequently acute food insecurity conditions (Kukal and Irmak 2018; Liu and Basso 2020). Changed air temperature patterns due to global warming did matter also as ecosystems are naturally well-adapted to given minimum, optimum, and maximum air temperatures, those of a weak resilience will, thus, simply extinct. In addition, global warming will induce more extreme climatic events like drought and floods; about 14–43% of the variability in yields of the main staple food crops in Ghana (groundnut, sorghum, millet, maize, and rice) could be explained by variability in temperature, number of dry days, onset, rainfall, and cessation (Baffour-Ata et al. 2021). Shall global warming be 3 °C, more than 50% of the agricultural lands in Brazil, China, Egypt, Ethiopia, and Ghana will suffer severe droughts of longer than one year, subjecting 80–100% of their populations to a longer severe drought condition, and, thus, food insecurity (Price et al. 2022).

Food security "*all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences*

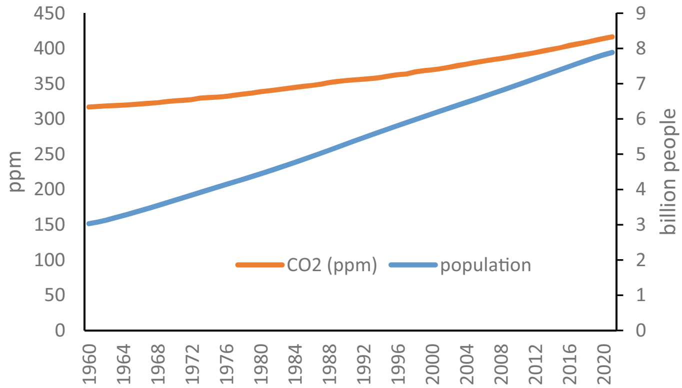


**Fig. 1** Increasing trends in global population and carbon dioxide at Mauna Loa, Hawaii. *Data source* The World Bank and Global Monitoring Laboratory. This figure is constructed by the author

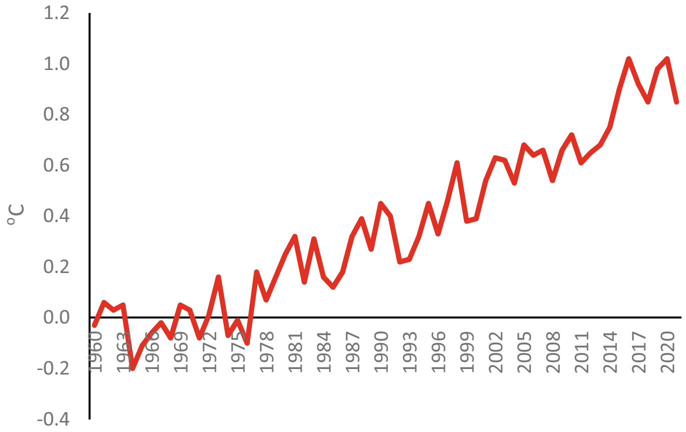


**Fig. 2** Anomalies in global annual surface temperature relative to the 1950–1980 average temperature. *Data source* NASA's Goddard Institute for Space Studies (GISS). This figure is constructed by the author

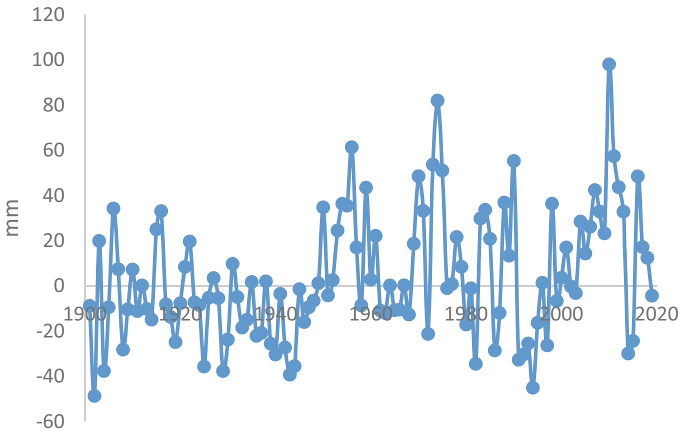


**Fig. 3** Anomalies in global precipitation (1900–2020). *Data source* Our World in Data. This figure is constructed by the author

*for an active and healthy life*" (FAO 1996) clenches, global attention. The World Food Program, WFP, (2023) underlined that 350 million people have been striving yet hunger and malnutrition, albeit with the concerted efforts made since the declaration of the United Nations Millennium Development Goal (MDG) "to half the number of hungry people", i.e. "*an individual's habitual food consumption is insufficient to provide the amount of dietary energy required to maintain a normal, active, and healthy life*" (Tirado et al. 2022); in 2015 this MDG has been replaced by sustainable development goals (SDGs), particularly SDG 2 "Zero hunger" by the year 2030. However, the probability of food insecurity remains high at $0.273 \pm 0.22$ on a global scale (Frongillo et al. 2019). Concerted efforts yet are urgently required to achieve SDG2 in the next seven years.

Unless mitigation and adaptation measures have taken immediately place, risks from climate change and variability would result in devastating consequences like famine; among these tangible, keeping pace, coping measures, early warning systems remain central and gripping much global attention for perceiving SDGs by the year 2030. This chapter synopses how early warning systems (EWS) contribute to food security; it also delimits the main components of EWS models; gaps, and opportunities to increase the effectiveness of food security EWS were also overviewed, alongside, a special reference goes to the food security early warning system in the Kingdom of Saudi Arabia.

## 2 Concepts of Early Warning System

The recent history of food information and early warning system has begun in the twentieth century, specifically at the World Food Conference, held in Rome in 1974 when the first universal objective to eliminate hunger has been declared in retort to the devastating rates of famine worldwide, especially in developing countries that kill over million people during the period 1970–1973. The establishment of the United Nations Food and Agriculture Organization (FAO) in 1945 could be considered a flipping point also in the history of the food security early warning system as national statistics on agriculture including food production have started to be adequately gathered and seriously well-thought-out in planning and distributing international fund and aid. However, gathered information has remained spatially limited, and time-consuming. Shamseddin and Adeeb (2012) stated that final estimates of rainfed crop yields were used to be available 2–3 months after harvesting time, based on the team survey mission approach (random cutting samples). However, real-time estimates have come to be easily accessible, costless, and more accurate nowadays because of the advanced technologies of data acquisition e.g. remote sensing and data analysis e.g. Geographical information systems (GIS), machine learning and artificial intelligence, which on the other hand, have eased and fastened the decision-making process to sustain food security or avoiding a dire state of insecure food conditions. This also is good advocacy for establishing a reliable food security early warning system (FSEWS) at national, regional and global levels.

The term "early warning system, EWS" itself is broad, but widely used in risk management. The United Nations Economic Commission for Europe (UNECE) segregated EWS into the following terms: *"Early" implies the time before the arrival of a hazard while there is still time to respond to the potential harm or loss. A "warning" is a communication protocol, a statement, or an event that warns of something or that serves as a cautionary example. A "system" is a standardized set of principles or procedures according to which something is done or an organized scheme or method*".

On the anniversary of World Meteorological Day 23rd March 2022 under the theme "Early Warning and Early Actions", the United Nations Secretary-General pledges that everyone on the globe should be attached to EWS in the next five years, especially the most vulnerable groups as yet 33% of the population worldwide is currently left without EWS. The sixth report of the IPCC on the impacts, adaptation, and vulnerability emphasized the dire need to stream EWS.

The early warning system is an effective risk management pathway. The objective of establishing a given EWS should be clearly stated. FAO (2000) ranked top the lack of a clear objective in the list of the main constraints associated with the food security early warning system. Hence, it is imperative to illustrate what risk means. The United Nations Office for Disaster Risk Reduction (UNDRR) defined comprehensively EWS as "*An integrated system of hazard monitoring, forecasting, and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enable individuals, communities, governments, businesses, and* *others to take timely action to reduce disaster risks in advance of hazardous events*". Šakić et al. (2022) defined EWS more simply as "*a system that provides us with warning information and gives time to take early action, to avoid unnecessary consequences*". These surfeit definitions unequivocally state that EWS is a complicated process, by which a series of actions and stakeholders are integrated to warn people in due time, allowing them to take necessary measures to prevent or minimize loss of life, infrastructure, and economic losses, among others. However, it is very difficult hitherto to build an effective EWS considering limitations in transforming the scientific-based evidence and lessons learned into understandable and transparent information for the public (Fearnley and Dixon 2020). A wide gap exists between citizens/beneficiaries and EWS findings due to poor mainstreaming of citizens in establishing EWS, a scientific-based claim by Marchezini et al. (2018); aligned with this, the World Bank report prepared by Braimoh et al. (2018) prefaced that acute food insecurity is escalated with poor data quality, inadequate analysis, poor dissemination/communication, weak mechanisms of coordination and response, and ineffective nexus of food information, trade policy, and private sector.

Long before then, EWS becomes an essential human right, lacking it, on the other hand, would inflict serious and deadliest risks, considering the frightening rates of natural and manmade hazards. However, having a reliable EWS will not be conceived overnight.

## *2.1 EWS Models*

Several models/structures for EWS were devised. The UNDRR categorized two models of EWS: (1) people-centered/end-to-end EWS with four key components, (a) risk knowledge, data collection and assessment of risk, (b) observing, and predicting of hazards and their likely impacts, (c) dissemination, and (d) preparedness; (2) Multi-hazard EWS which allows warning of more than one hazard. Khankeh et al. (2019) have reviewed the EWS models applied worldwide in emergencies and disasters during the period 1980–2019; they stated the lack of a large consensus on the main components of EWS. Diverse structures of EWS models existed because of the disparities in the main objective of the EWS as some models did concentrate only on hazard identification while the remaining focused on warning and response (Khankeh et al. 2019).

EWS models are generally composed of four basic elements: (a) knowledge of risk, (b) monitoring and forecasting, (c) dissemination and communication, and (d) response-ability (de Perez et al. 2022); there is a wide room also to subset these basic elements, which would result in a number of divergent EWS models, however. Figure 4 demonstrates the basic components of EWS. It starts with the risk knowledge process. The sixth report of the IPCC defines risk as "*the potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems*". The definition is headed by the term

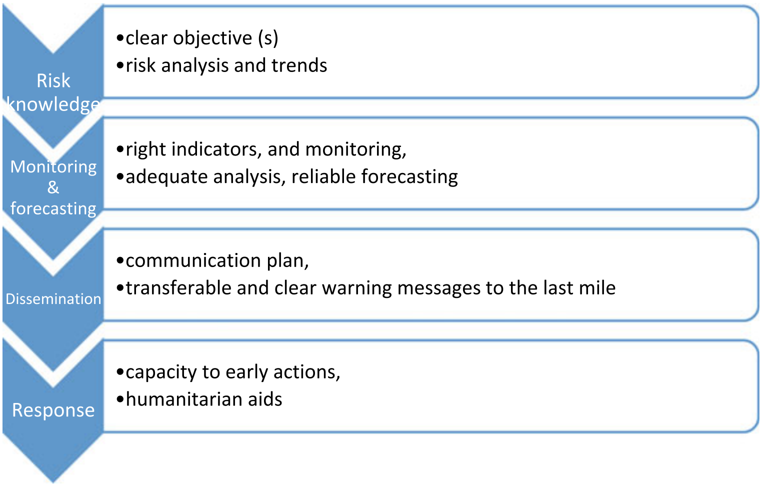


**Fig. 4** The four basic components of early warning systems, commence with risk knowledge, followed by monitoring and forecasting, dissemination, and response. This figure is constructed by the author

"*potential*" which intrinsically implies complications related to "*uncertainty*". Operationally, the "*risk*" is the result of interactions among "*hazard*, i.e. a risk source like floods and. drought", "*exposure to risk*", and "*adaptive capacity*", i.e.

$$\text{Risk} = \text{hazard} + \text{exposure} + \text{sensitivity} + \text{adaptive capacity}$$
$$\text{Vulnerability} = \text{sensitivity} + \text{adaptive capacity}$$

This illustration definition tells us that risk is a dynamic combination effect of four determinants. Cardona et al. (2012) defined these factors as follows:

***Hazard*** is "*the possible, future occurrence of natural or human-induced physical events that may have adverse effects on vulnerable and exposed elements*".

**Exposure** is "*the inventory of elements in an area in which hazard events may occur*".

**Adaptive capacity** is "*the positive features of people's characteristics that may reduce the risk posed by a certain hazard*".

Sensitivity or fragility is "*physical predisposition of human beings, infrastructure, and environment to be affected by a dangerous phenomenon due to lack of resistance and predisposition of society and ecosystems to suffer harm as a consequence of intrinsic and context conditions making it plausible that such systems once impacted will collapse or experience major harm and damage due to the influence of a hazard event*".

**Vulnerability** is "*the propensity of exposed elements such as human beings, their livelihoods, and assets to suffer adverse effects when impacted by hazard events*".

Accordingly, the higher the exposure and sensitivity and the lower the pre-existing adaptive capacity, the exaggerated hazard's brunt and the higher the disaster risk, and vice versa thus, mitigation and adaptation measures like early warning systems are crucial for risk management. Therewith, risk knowledge, and assessment (characterization of potential adverse impacts) are yet standing challenges; Braimoh et al. (2018) summarized that, concerning food security, 29% of the respondents did claim that they doubt that hazards are regularly evaluated in the East and South Africa regions. Agriculture is endowed with intrinsic risks and uncertainty as several physical and nonphysical dimensions are cross-cutting; currently, a platform for sharing knowledge and experience called "Forum for Agricultural Risk Management in Development, abbreviated as FARM" is publicly accessible (www.agriskmanagementforum.org). The second component of EWS is the monitoring, analysis, and forecasting, which is a continuous daunting process, bearing in mind the dynamic nature of hazards like uprising air temperature; building an extended meteorological network is thus crucial for having reliable forecasting concerning food security. Collection of datasets per se is not the ultimate objective rather adequate analysis does the matter. The third component of EWS is the dissemination and communication as gained information from early warning systems' dashboards are generally deeply high-technical-profile outputs and thus should be transformed into understandable messages to decision-makers and end-users. However, such transformation is yet at an infancy stage; for instance, over the whole East and South Africa regions, early warning outputs were only personalized to people at risk in Kenya and Swaziland (Braimoh et al. 2018). The fourth component of EWS is the response, which is the ultimate objective of the early warning system; the effective response revolves around capacity buildings on how communities should respond to warning signals in an organized manner, better preparedness, and humanitarian aid. de Perez et al. (2022) argued that dissemination and communication, and response capability were the weakest points in the adopted EWS worldwide with wide opportunities to improve the performance of the remaining components. Another important point that had better be raised here is how the term "hazard" is being defined by the developed EWS.

The developed EWS model of the Signature Program of the United Nations Development Program, UNDP (i.e. a special program designed to increase the resilience and adaptation to climate change in Africa, Asia, and the Pacific through information and EWS) was based on "*integrates the components of risk knowledge, monitoring and predicting, dissemination of information and response to warnings*"; the evaluation of this EWS model stands on the performance assessment of the four main processes (knowledge, monitoring and predicting, dissemination, and response), and the integration process.

## 3 Metrics and Indices of Food security

There is no wide consensus yet on how food security could be measured. Jones et al. (2013) wrote that "*the diversity of food security measurement tools currently available provides a rather dizzying array of options, such that it may not always be clear how the measures differ in their conceptualizations of food security and for what purpose a given tool may best be used*"; Thus, the following pitfalls should be strictly avoided in selecting food security metrics (after Jones et al. 2013):

(a) quantifying an unintentional food security domain;
(b) metric several domains with no capacity to distinguish between them;
(c) gathering irrelevant datasets
(d) collecting datasets from incorrect scales;
(e) assembling datasets that cannot be repeated many times
(f) picking an inappropriate tool as some may necessitate resources beyond the capacity
(g) selection of insensitive indicators

The key component in measuring food security is the well-defined objective (tactical or strategic). Jones et al. (2013) tabulated the main components in measuring food security, viz. metric, measurement, data source, spatial and temporal scales, domain, and objective. For instance, the objectives of the undernourishment prevalence metric are monitoring progress in SDG 2 and setting food policies (for more details readers are referred to Jones et al. 2013). The household survey represents a central data source on food security, including income, food expenditure, food utilization, coping, and hygiene. Divergent food security indices existed with major differences in their scale, i.e. individual, household, national, regional, and global; the calculation of these indices might pose real challenges, especially with those applying a multi-criteria assessment. Of these indices are:

**Undernourishment/malnutrition**. It is "*a state resulting from lack of intake or uptake of nutrition that leads to altered body composition (decreased fat-free mass) and body cell mass leading to diminished physical and mental function and impaired clinical outcome from disease*" (Serón-Arbeloa et al. 2022). The nutrition term implies the basic food components, protein, energy, minerals, vitamins, etc. Thus, complicated (e.g. imaging, and malnutrition universal screening test) and simplified (e.g. simplified nutritional appetite questionnaire) tools for determining this food security measure were tested worldwide.

***Dietary diversity***. it is "*a qualitative measure of food consumption that reflects household access to a variety of foods, and is also a proxy for nutrient adequacy of the diet of individuals*" (FAO 2013). This measure is normally assessed via a special-designed household questionnaire.

***The Household Food Insecurity Access Scale (HFIAS)***. Albeit with the abundant food production, households may face real challenges to access it. The HFIAS is used to assess the household's food accessibility. It assesses uncertainty or anxiety in the food supply, quality, and utilization (Kabalo et al. 2019). A household survey is the data source of this scale. Hanmer et al. (2021) assessed HFIAS via the household's response to three main questions: "*(1) worried whether your food would run out before you had money to buy more* in the last 12 months *(2) the food that you bought did not last, and you didn't have enough money to get more, or (3) you couldn't afford to eat balanced meals*".

***Food consumption score***. Food aid actions of the World Food Programme (WFP) are based on this index "*how often households consume food items from the different food groups during a 7-day reference period*". The final score of this index is composed of households' survey-based information: *dietary diversity, food frequency, and relative nutritional importance of different food groups* (WFP 2023).

***Global Hunger Inde*** While the keyword in this index is "hunger", however, its calculation is based on scoring four criteria/indicators, viz. undernourishment, child stunting, child wasting, and child mortality (www.globalhungerindeorg). The index is also applied at a country level as well as at a global one.

***IPC***. In 2004, the FAO developed a multi-stakeholder framework for mapping food security and nutrition, called Integrated Food Security Phase Classification (IPC); the IPC is implemented normally by national and global steering committees. The use of this approach has been uprising among the community of practice worldwide, especially the humanitarian aid agencies that are active in Africa and Latin America. The IPC website summarizes the main characteristics of the IPC as follows:

- *a process to build evidence-based technical consensus among key stakeholders;*
- *an approach to consolidate wide-ranging evidence to classify the severity and magnitude and to identify the key drivers of food insecurity and malnutrition;*
- *a path to provide actionable knowledge for strategic decision-making;*
- *a platform to ensure a rigorous, neutral analysis.*

The IPC commonly classifies crises of food security into acute food insecurity, chronic food insecurity, and acute malnutrition. Acute food insecurity is being scaled into five phases (from none to famine), four phases for chronic food insecurity (minimal to severe), and five phases for acute malnutrition (acceptable to severe). This phase-based classification allows better understanding, decision-making, planning, and response. The implementation of IPC, by the national technical working group, is iterative learning (plan, prepare, analysis, and learn), multi-stakeholder, and quality assurance fashioned.

## 4 Food Security Early Warning System

The vogue definition of food security "*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*" is generally attracting four strategic food dimensions: availability, stability, access, and safe utilization of food (FAO 2000). These dimensions, however, increase as the spatial scale decreases since the national food security definition is downscaled to "*food production, supply, and sale are in a state of no danger and threat*" (Sun et al. 2022). The term "food production" empowers the dimension of "sovereignty" which is defined as "*the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems*" (Jones et al. 2015). This sovereignty aspect, thus, involves further central facets: Food as a basic human right, farming reorganizations, sustainability of natural resources, national food trade policy and involvement of the private sector to sustain local food production systems, decreasing multinational attentiveness of power, building peace, and participation of stakeholders in the decision-making process (Sampson et al. 2021). It is therefore, some specialists call for toting the agency i.e. "*empowerment of local communities in food security and nutrition*" to the basic four strategic objectives of the global definition of food security (Sampson et al. 2021). However, evidence stated the weak relationship between improved human health and food sovereignty. Deng et al. (2022) appealed that the heterogeneity in food security increases as the spatial scale decreases due to the increased brunt of local drivers e.g. climate, socioeconomic, tertiary industry, agricultural outputs, and among others. The scale of Food security is segregated into micro (individual, and household), meso scale (national), and macro (regional and global). Accordingly, any food security early warning system (FSEWS) should thus cogitate these operational objectives and scales. Ammar et al. (2023) suggested an analytical food security framework that integrates global and national levels based on big data (e.g. agriculture) analysis and modeling (e.g. GAMS), indicators, gaps identification, policies, and drivers.

Food security is a complicated, multidisciplinary concept. Raised awareness on sustainability and climate change, thus, calling for the compelling need for a newer working definition. Aligned with this, the Economist Impact is indexing food security at country and global levels based on affordability, availability, quality and safety, and sustainability and adaptation. Analogous to the sustainable energy EWS Framework suggested by the United Nations Economic Commission for Europe (UNECE), the author does stress that a sustainable and working definition of FSEWS should permit the following four pillars (Fig. 5):

(a) food supply
(b) sustainability intensification,
(c) economic prosperity, and
(d) quality of life.

### *4.1 Food Supply*

The food security concept has emerged to replace the limited term of food supply since the 1970s. The term food supply, hereafter, integrates the historical four pillars of food security: availability, stability, access, and utilization.

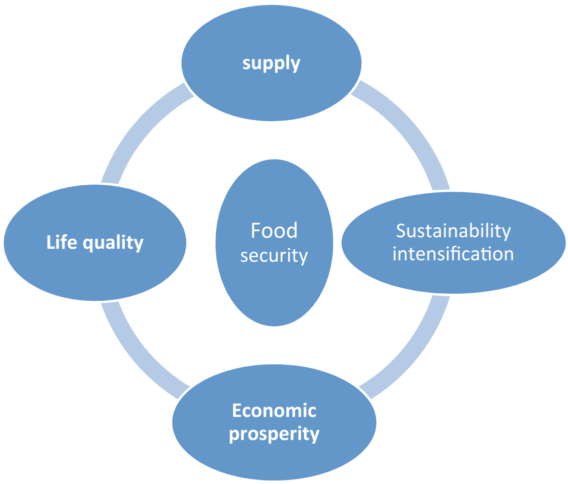


**Fig. 5** The adapted pillars for achieving a sustainable food security, as suggested by the author. *Source* This figure is constructed by the author

#### 4.1.1 *Food Availability*

Is designated as "*the physical existence and how food is supplied from production and/or cultivation to marketing*" (de Oliveira Veras et al. 2021). This "physical existence" normally refers to cereal and animal production. The key role of EWS in this food supply pillar is the provision of reliable forecasting that allows decision-makers to respond quickly as well as better planning. The term "forecast" is a statement of likely expected conditions (e.g. meteorological) for a given period in a given location (after Braimoh et al. 2018). Reliable Forecasting, however, depends on the adequate collection and analysis of quality datasets as well as the selection of appropriate indicators. The FAO (2000), for example, suggested inter-alia the use of trend analysis of prices, heifers' sales by local people, and conditions of infrastructures for building reliable forecasting. The use of advanced remote sensing, GIS, and machine learning algorithms has increased forecasting reliability (Bouaziz et al. 2021; Herath et al. 2021; Mosaffa et al. 2022; Shen et al. 2021); the application of Random Forest machine learning algorithm coupled with remote sensing information has resulted in an effective monitored drought events without the need for ground-truth observations (Zhao et al. 2022); also, reliable automated estimates of crop yield were recently generated based on artificial intelligence and remote sensing (Hyas et al. 2023).

Crop Yield Forecasting

Crop yield forecasting/prediction is the heart of FSEWS. Two forecasting pathways are currently applied in crop yields (Shamseddin 2021); statistical regression and growth simulation models. The statistical crop yield models are generally functions/regressions on weather variables, especially surface air temperature, and precipitation (Ceglar et al. 2017; Conradt 2021; González-Fernández et al. 2020; Kern et al. 2018;

Lecerf et al. 2019; Shamseddin 2021). Albers et al. (2017) accounted for the impacts of weather variability on wheat yield at 43% in Germany. However, difficult to interpret the results, and the sensitivity of the model to changes in the climate, scale, trend, collinearity, and inconsideration of adaptation measures like rainwater harvesting are the main constraints facing the application of regression models in crop yield forecasting (Gornott and Wechsung 2016; Shamseddin 2021; Shi et al. 2013). The two schools of thought on crop yield regression are summarized as follows (Agnolucci and De Lipsis 2020; Shamseddin 2021):

$$Y_T = \overline{Y} + f(T) + e \tag{1}$$

$$Y_T = b_o + f(T) + f(weather) + e \tag{2}$$

In which, ($\overline{Y}$) is the average crop yield, f(T) is the linear time-trend function, and e is the **independent** residual error or the weathering variability brunt, i.e. e = *f(weather) = observed yield – estimated yield*. Equation (2) states that the function of time trend is a **dependent** variable and has to be well-considered, b0 is the crop yield under no trend and weather impacts. Figure 6 presents the validation results of a developed stepwise regression model of wheat yields in Egypt by Shamseddin (2021); the model was based on Eq. (1), by which a detrending process was mainly generated to get rid of the impacts of technologies and improved practices, thus, the yield variability is only affected by the climate variability; the model states that the country-wide mean air temperature is the most influencing factor, through which 20% of the variability in yields is explained. The model's performance could be substantially improved shall finer spatial datasets be used instead of country-wide ones. Machine learning algorithms could be also to better understand climate variability and crop yields.

The growth models like WOFOST and Aquacrop are process-based simulations, relating a crop yield with its prevailed environmental conditions; their wide applications, however, were hindered by the limited availability of finer datasets e.g. crop. management, weather, and soil, among others (Geneille and Wang 2016; Pagani et al. 2017; Sultan et al. 2019). Remote sensing has been extensively used to avail high-resolution datasets like the normalized difference vegetation index, NDVI (Kasampalis et al. 2018). A good application example of remote sensing on food security early warning is the ASAP project (Anomaly Hotspots Agricultural Production), commissioned by the European Commission. The most recent ASAP release (8th May 2023) projected poor cereal yields in the Maghreb region, east Africa region, Namibia, and southern Angola, with seasonal droughts in Haiti (https://mars.jrc.ec.europa.eu/asap/).

Estimates of global crop yields are also crucial for countries where food productions are virtual water-dependent, i.e. food imports. The forecasting of food supply in this case, however, should ponder externalities that influence the supply chain, COVID-19 and the Ukrainian-Russian war are vivid examples of the detrimental impacts of such externalities.

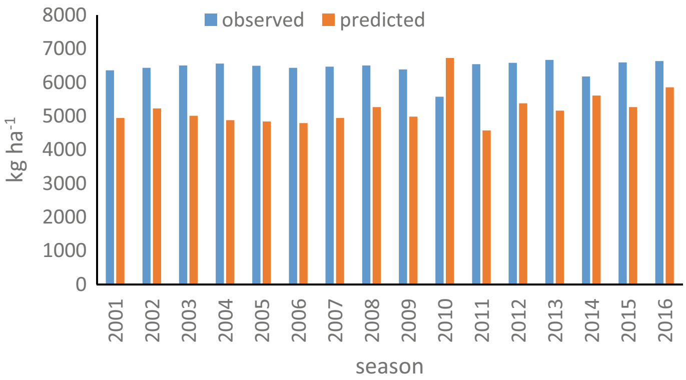


**Fig. 6** Validation of a developed stepwise regression model of wheat yields in Egypt ($R^2 = 0.20$, RMSE = 1058.4 kg $ha^{-1}$). The prediction could be much improved shall a finer spatial resolution be applied, compared to the national scale. *Data source* After Shamseddin (2021). This figure is constructed by the author

Which one to select and apply regression or simulation model is user and site-dependent; whether regressed or simulated, the crop yield forecasting prediction requires good infrastructure and institutions, including high-profile skills.

Of much importance also is the high losses along the food supply chain, which were estimated at one-third of the global food produced. The review of 141 peer-reviewed papers on drivers of food security revealed that enacted policies of food losses and waste were ranked top (Wahbeh et al. 2022).

### 4.1.2 Food Stability

It is designated as "*a population, a household, or a person must always have access to adequate food to have food security*" (Gonçalves et al. 2021). The stability of the food supply is largely dependent on the sustainable mitigation and adaptation measures taken in the face of the likely risks, particularly climate change and variability; a feasibility study on multi-sectoral climate change adaptations for food security and nutrition has categorized the improved access to "early warning and early action" as one of the highest feasible adaptation measures (Tirado et al. 2022). For example, it is well-known that a deficiency in irrigation water of more than 50% would trigger an agricultural drought, which is resulting in low crop yields; in this case, establishing a reliable drought early warning system remains a sustainable mitigation measure. Other mitigation and adaptation measures include the adoption of "biosecurity" for maintaining animal production, defined as "*a set of measures taken to block the admission of a disease into a farm*" (Gonçalves et al. 2021). Food stability is also very sensitive to producers' financial literacy and capability (Wulandari et al. 2017); the regression of the food production index (dependent variable) on selected economic indicators, i.e. food imports, food exports, food price inflation, and extreme monetary poverty (independent variables) showed that the extreme monetary poverty is the only significant one in two developing countries as follows (Bozsik et al. 2022):

For Columbia:

$$PI = 100.5 - 2.41 * EMP \quad R^2 = 0.84 \tag{3}$$

For Kyrgyzstan.

$$PI = 117.1 - 1.37 * EMP \quad R^2 = 0.71 \tag{4}$$

where PI is the food production index, and EMP is the extreme monetary poverty index Eqs. (3–4) stated the negative relationship between the food production index and extreme monetary poverty as crop yields would be significantly reduced once agricultural inputs weren't secured in due time. Furthermore, in several cases, agricultural drought was just the direct result of a late sowing, date because solely of financial limitations rather than the physical irrigation water availability. Contractual agriculture is being practiced worldwide to bound such financial challenges facing, especially for small farmers and livestock producers. Food early warning systems should, thus, consider these adaptation measures in indicating food stability.

### 4.1.3 Food Access

Is simply demarcated as "*people's access to adequate resources to acquire appropriate food and a nutritious diet*" (Gonçalves et al. 2021), or it is comprehensively meant that "*the resources to obtain sufficient quality and quantity for a nutritious diet and still consider economic, cultural, and social aspects that may interfere with the purchase of goods*" (de Oliveira Veras et al.2021). Thus, FSEWS should also comprise socioeconomic indicators to warn of food crises due to limitations in access by households despite the physical availability and stability of food. Political instability (e.g. conflicts) has overburdened also food access; Guiné et al. (2021) signified that political stability and food availability were the central factors in controlling malnutrition rather than the gross domestic product, GDP. Therefore, any effective FSEWS should incorporate political stability indicators.

### 4.1.4 Consumption/Utilization

Is stressing the central role of non-food factors in food security. The biological utilization of food is defined as "*the biological use of food through adequate nutrition, drinking water, sanitation, and medical care, to achieve a state of nutritional well-being in which all physiological needs are satisfied*" (Gonçalves et al. 2021). The definition also highlights the importance of drinking water and hygiene practices in achieving food security. To get rid of food and water-borne diseases like diarrhea, currently, intense capacity-building programs on Water, Sanitation, and Hygiene

(WASH) are running, especially at school levels worldwide. Accordingly, utilized food should be of good quality, safe, healthy, and nutritious status (FAO 2000). Any FSEWS should have thus to include health and nutrition indicators, by which malnutrition could be earlier warned. The health and nutrition indicator (mostly based on household surveys and records) alerts also the obesity prevalence, not just the deficiency. This food utilization is strongly interlinked with the quality of life (QoL), which is discussed in more detail below.

## *4.2 Sustainability Intensification (SI)*

There are mounted stresses to increase agricultural production with minimum adverse impacts on environments and ecosystems. Subsequently, the sustainability intensification (SI) term was induced "*increase the production with reduced negative environmental impacts on the same land at the same time*" (Aznar-Sánchez et al. 2020). The realization of SI is based on the food-environment-climate change nexus as agriculture remains the largest contributor to GHG emissions. The concept of "Smart agriculture ("*a farm management concept that may use the Internet of Things (IoT) to overcome the current challenges of food production*", Navarro et al. 2020) has yet the best-recommended path to realize SI; examples of SI approaches, especially for small-holder farmers, embrace integrated land and water management practices like rainwater harvesting, increase the diversification of agricultural systems, and integrated pest management (Ajibade et al. 2023). In this regard, the World Bank initiated the "*Food System 2030 Trust Fund*" to help countries in transforming and improving their food systems "*from farm to fork*" by the year 2030.

Food security has had also a great impact on the water and energy sectors. Thus, the food security-water-energy nexus concept has been developed, articulated as "*the study of the connections between these three resource sectors, together with the synergies, conflicts, and trade-offs that arise from how they are managed, i.e., water for food and food for water, energy for water and water for energy, and food for energy and energy for food* (Simpson and Jewitt 2019); however, despite its intuitive meaning, the interpretation and implementation of this concept are controversial yet (Simpson and Jewitt 2019). Whatever the case, food security policies and programs should be well aligned with the water and energy ones.

## *4.3 Economic Prosperity*

SDG 8 promotes "*inclusive and sustainable economic growth, employment, and decent work for all*". The World Bank database estimated the global workforce in agriculture at 27% in 2019, approximating also the contribution of agriculture to global GDP at 4%, and 25% in developing countries. Thus, food security, the economy, and sustainable development are strongly interconnected. Wudil et al.

(2022) stated that food security is worsened due to the weak economic growth in Sub-Saharan Africa. Bozsik et al. (2022) stated that access is a food production determinant factor, calling for better integration among food security, monetary and trade policies. This supports the claim by the World Bank that "*Agriculture can help reduce poverty, raise incomes and improve food security for 80% of the world's poor, who live in rural areas and work mainly in farming*". Interestingly, Ceesay and Ben Omar (2022) evidenced that while food security sustains the expansion of per capita GDP, however, vice versa holds not true, based on the Granger Causality test. This implies that food security is the driver for achieving economic growth. Wahbeh et al. (2022) reported, however, that food demand expands as the economy expands. Accordingly, the community of practice should be unequivocally aligned with food security and poverty reduction action programs; this holds also for international donors. A solid basis for agricultural economic early warning systems exists; Yang (2021) developed a reliable agricultural economic intelligence information EWS (with a prediction accuracy of 99%). Regression models have been largely used in connecting food security with economic indicators like food price inflation, food import dependency, and food balance trade, among others (Bozsik et al. 2022).

### *4.4 Quality of Life (QoL)*

The QoL is conceptualized as "*a multi-dimensional concept of an individual's general well-being status in relation to the value, environment, cultural and social context in which they live*" (Phyo et al. 2020). SDG 3 is assigned to good health and well-being. Food security promotes a healthy life, especially for vulnerable groups (e.g. children and adults). A strong negative correlation is detected between the prevalence of food insecurity and "subjective" well-being across 147 countries, based on a hedonic adaptation measure, i.e. *People compare their well-being to a subjective reference that adjusts over time* (Frongillo et al. 2019). Not only physical health but food insecurity was associated with mental health also, which is largely not easily detected by normative socioeconomic and demographic factors (Bhandari et al. 2023). Because of the adverse impacts of food insecurity on QoL, the participation of adults in social roles is limited (Hanmer et al. 2021). A cross-sectional study stated that factors e.g. education, occupation, and income that could adversely impact diet quality and anthropometric indices contributed to poor health status at a household scale (Ebadi-Vanestanagh et al. 2019).

While the definition of QoL implies different perspectives, however, datasets of PROMIS (Patient Reported Outcomes Measurement Information System) domains could be easily adapted and used in FSEWS (Hanmer et al. 2021).

# 5 Applied Examples of Food Security Early Warning System

## 5.1 East and South Africa Regions

The World Bank concerned with the contribution of EWS to food security in the East and South Africa regions since the 1970s, supported by several international agencies (e.g. FAO, WFP, and Humanitarian early warning service) as well as national ones (Meteorological authorities). The establishment of FSEWES has deeply been painstaking in the social aspects of the targeted communities, with special reference to vulnerability and resilience to natural hazards. High resolutions (15 × 15 km), satellite and ancillary data-based, seasonal forecasting of climate is assured and made available by regional and global service centers. Based on this seasonal forecasting, agricultural (e.g. crops to grow) and health (e.g. malaria control) plans were developed. The risk information for FSEWS is generated through different themes (i.e. hydro meteorological, pest, productions, market, and vulnerability). The hydro-meteorological theme, for forecasting purposes, could be achieved through a reliable modeling method based on hydro-meteorological indicators like rainfall and temperature (Braimoh et al. 2018). Consequently, biannual regional and national food security maps are generated, based on the IPC. This FSEWS is faced with many challenges like limited technical and financial resources, limited weather station networks, dependency on external resources, and poor coordination, especially between farmers and governmental bodies. The Hydromet scheme (Hydro-meteorological Monitoring System) that is initiated by the Nile Basin Initiative over its ten states, is expected to improve hydro-meteorological data availability over the region.

East and South African regions have been subjected to repeated drought cycles that seriously jeopardized food security. Thus, the region is a major beneficiary of the United States Agency for International Development's Famine Early Warning Systems Network (FEWS NET) which offers a Drought Early Warning System for better understanding, monitoring, modeling, and forecasting food insecurity, based on remote sensing, climate prediction, agroclimatology monitoring, and hydrologic modeling (Funk et al. 2019). The network also provides food insecurity alerts based on IPC protocol. Backer and Billing (2021) estimated the accuracy of the FEWS NET at 84%, claiming that the projected food security is largely affected by overestimated severe food insecurity as well as conflicts, and El-Niño phenomena.

## 5.2 The Kingdom of Saudi Arabia

Food production in the Kingdom of Saudi Arabia (KSA) faces real challenges. The country is endowed with a desert climate, except for the southwestern region (semi-dry). Monthly rainfall is seasonal, erratic, and limited, ranging between 0.73 and

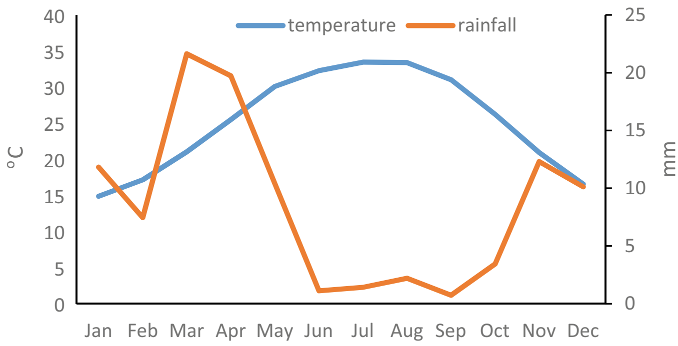


**Fig. 7** A country-wide monthly means of air temperature and rainfall in Kingdom of Saudi Arabia (1901–2021). *Data source* Climate Research Unit (CRU). This figure is constructed by the author

21.6 mm (totaling 102 mm a year); monthly air temperature ranges from 14.9 °C (winter) to 33.5 °C (summer) (Fig. 7). Accordingly, monthly water balance is negative due to high evapotranspiration rates. Thus, excessive use of groundwater predominates in agricultural production.

Climate change is projected to have adverse impacts with a 51% reduction in annual rainfalls coupled with an increase of 2.1 °C in air temperature by the year 2100, based on the ensemble mean (Fig. 8). The country is characterized also by its very limited arable land (desert) and high-salinity issues (soil and water). The country's 2030 strategic vision, thus, strictly emphasized the sustainable use of water resources (especially groundwater) coupled with a zero GHG emission plan by the year 2060. The national agricultural transformation program is undergoing, thus, expanding the adoption of advanced technologies and sustainable practices (e.g. sub-surface irrigation, organic agriculture, the internet of things, tertiary wastewater treatment, desalinization technologies, and capacity buildings, among others) would ultimately achieve food security, economic growth, and quality of life with zero adverse environmental and health impacts (i.e. sustainability intensification and green economy).

### 5.2.1 FSEWS in KSA

The current digital transformation and revolution of agriculture in KSA made having reliable forecasting of agricultural productions, including livestock much conceivable, through the application of the crop growth simulation models as voluminous finer information is available, especially for the greenhouses production. However, food self-sufficiency remains cumbersome. Self-sufficiency is estimated at < 30% for cereal (except for sorghum of 98%), 29–100% for vegetables, 16–110% for fruits, and 37–123% for animal products (Fiaz et al. 2018). Thus, gaps in the food supply are met by importation, having regard that KSA is a G20 country coupled with the strong political will for sustaining supply chains. Of many important points to

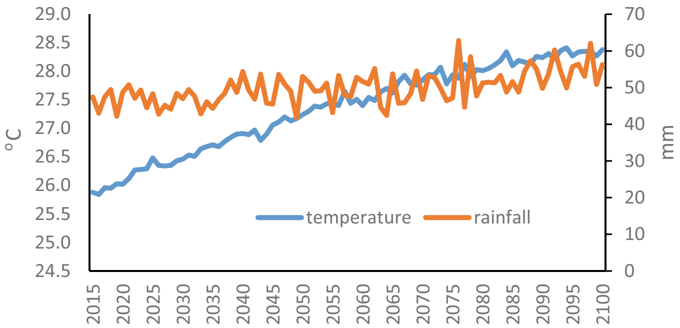


**Fig. 8** Multi-model ensemble means of air temperature and rainfall in the Kingdom of Saudi Arabia by the year 2100, based on RCP 4.5. *Data source* CMIP6. This figure is constructed by the author

mention here is food waste. Sobaih (2023) reported that food waste constitutes 50% of the overall waste, equivalent to 40 billion SR, with a per capita food waste of 250 kg $yr^{-1}$ in KSA, compared to the global one of 114 kg $yr^{-1}$. This problem is intensified amidst the COVID-19 pandemic, which is associated with cultural and food consumption behavior changes, let alone its detrimental impacts on food supply chains. These issues shouldn't be overlooked in the intended FSEWS in KSA, and their engagement prerequisite conducting a SWOT analysis (Strengths, weaknesses, opportunities, and threats).

In Table 1, an adaptive framework and pillar of FSEWS for KSA is suggested. Selected examples of objectives, methods, indicators, and impacts were presented. The selection of sensitive indicators is a crucial step for attaining effective FSEWS; any objective should be associated with a well-defined and precise objective. Figure 9 proposes the framework of the suggested FSEWS for KSA. However, the final components and the institutionalization of this suggested framework need further proactive consultation and integration among the acting bodies, started by national and regional workshops as well as focus discussion groups. Generally, the framework should be segregated into national, regional, and local levels, within which the flow of information and responsibility should be well-defined.

**Table 1** Proposed sustainable food security early warning system pillars in the Kingdom of Saudi Arabia

| Pillar | Objective | Method | Indicators | Impact |
|---|---|---|---|---|
| Risk knowledge | Food security risks spectrum | Modeling, focus discussion group | Institutions and people awareness | Clear objectives, participation, coordination, governance, responsibility |
| Supply (availability, stability, access, and utilization) | Reliable prediction and vulnerability | Cloud-based modeling, and survey | Yields, livestock production, stocks, access to markets, in–out flows of production, dietary demand, and pests and diseases, supply chains, political stability | Agricultural plans (e.g. cultivated areas and type of crops), and food balance sheets |
| Sustainability intensifications | Minimizing adverse environmental impacts | Modeling and survey | Emissions, adoption of advanced technologies, integrated pests and diseases management, tertiary treated and recycled wastewater and rainwater harvesting | Enabled environment |
| Economic prosperity | Economic growth | Modeling and survey | Market price, inputs' cost, GDP | Green economic growth |
| Quality of life | Ensure food security health related-quality of life | Survey and promis | Health-related—QoL protocols, (mortality, mental health, obesity, malnourished prevalence among vulnerable groups), access to health cares, sports and park-based activities | Triggers QoL enablers |

(continued)

**Table 1** (continued)

| Pillar | Objective | Method | Indicators | Impact |
|---|---|---|---|---|
| Dissemination and communication | Understandable alerts to end users | Communication technologies and equipment | Multiple dissemination outlets | Exchange information, improved community's capacity to response |
| Response | Vulnerability assessment | Assessment and survey | Agricultural production, climate, socioeconomic, and anthropometry | Defined vulnerable regions, communities, and households; preparedness plans |

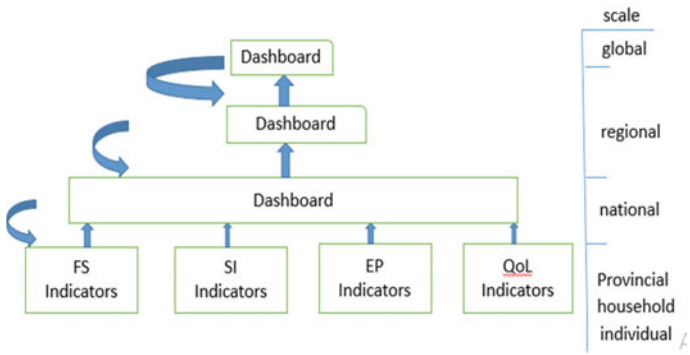


**Fig. 9** A conceptual adaptive food security early warning system framework. FS stands for food supply, SI for sustainability intensification, EP for economic prosperity, and QoL for quality of life. *Source* This figure is constructed by the author

# 6 Conclusion

Food security and nutrition grasp global attention and are strongly incorporated into SDGs. Increasing the adoption and reliability of early warning systems have recently gained a global commitment in response to escalated calamities, climate change, natural hazards, and sustainability which, on the other hand, necessitate revisiting the olden food security definition. This chapter suggests that the sustainable food security early warning system (FSEWS) should serve four pillars: food supply, sustainability intensification, economic prosperity, and quality of life. Opportunities exist to enhance the effectiveness of FSEWS by filling gaps in quality data acquisition, data analysis, dissemination and communication, coordination among stakeholders, participation of all stakeholders, adaptation measures, and risk awareness. Establishing a reliable FSEWS is adaptive, depending on sharing experiences, lessons learned, and partnerships at global, regional, national, and local levels.

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# Chapter 13
# Food Consumption Patterns in Saudi Arabia

**Abdalbasit Mariod, Haroon Elrasheid Tahir, and Suzy Salama**

**Abstract** The Kingdom of Saudi Arabia has been interested in supporting innovation, research, and technology for the sustainable transformation of local food production systems and diet patterns. The country has a rich heritage in the field of dietary patterns extending through historical eras, which included many aspects of the social life of the Saudi people, which all families were keen to pass on from generation to generation so that it would remain alive in their hearts. One of the biggest importers of food is the Kingdom of Saudi Arabia. The Saudi society is also a consumer society, and many diseases linked to bad eating habits, such as eating fatty foods, saturated fats, fast food, ready-made foods, and others, have shown up. A healthy lifestyle includes several healthy choices, including choosing a balanced diet. It also includes a healthy eating plan that helps control weight by eating a variety of foods. Eating a healthy diet helps prevent malnutrition in all its forms, as well as non-communicable diseases. This chapter sheds light on most food patterns and the type of meals in the Kingdom of Saudi Arabia to identify their nutritional value and the extent of their connection to the knowledge heritage of Saudi society, which may help in the development of these patterns.

**Keywords** Breakfast · Dishes · Hedonic test · Lunch · *Nigella sativa* · Olive oil · Panelist · Saudi · Traditional

A. Mariod (✉)
Biological Department, College of Science, University of Jeddah, Jeddah, Saudi Arabia
e-mail: aalnadif@uj.edu.sa

A. Mariod · S. Salama
Indigenous Knowledge and Heritage Centre, Ghibaish College of Science and Technology, 110, The Eastern Neighborhood Next to Donki Almarai, Ghibaish, Sudan
e-mail: s.salama999@gmail.com

H. E. Tahir
School of Food and Biological Engineering, Jiangsu University, Zhenjiang 212013, Jiangsu, China
e-mail: haroona28@ujs.edu.cn

S. Salama
Indigenous Knowledge and Heritage Centre, Ghibaish College of Science and Technology, 110, The Eastern Neighborhood Next to Donki Almarai, Ghibaish, Sudan



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## 1 Introduction

A dietary pattern can be defined as the amount or variety of foods and drinks in a diet that are usually consumed frequently (Schulze et al. 2018). Eating a healthy diet helps prevent malnutrition in all its forms, as well as non-communicable diseases, including diabetes, heart disease, stroke, and cancer. Unhealthy diet and lack of physical activity are among the most prominent global risks to health (Wells et al. 2020). Healthy eating practices begin early—breastfeeding promotes healthy growth and improves cognitive development and may have longer-term health benefits such as reducing the risk of becoming overweight or obese and developing non-communicable diseases later in life (Khodaee et al. 2015). However, increased production of processed food, rapid urbanization and changing lifestyles have all led to a shift in dietary patterns. People are now consuming more foods that are high in energy, fat, free sugars and salt/sodium, and many people don't eat enough fruits, vegetables, and other dietary fiber such as whole grains (Vorster 2008).

Diet plays an important role in protecting humans from chronic diseases, and it is possible to stay away from the risk of diseases by eating diets rich in vegetables, fruits, legumes, nuts, and grains, as well as reducing salt and sugar, and choosing unsaturated fats instead of saturated fats to reduce trans fats while being careful to reduce the amount of fat consumed in general (Brand-Miller 2003).

The increasing consumption of fast and easy-to-cook foods is a common phenomenon worldwide because of due to the great changes in these societies in the living patterns in the modern era, as the shift from eating natural or processed food to a large extent, which is characterized by containing more energy and less dietary fiber. The increased consumption of fast-food meals in KSA in recent times has an impact on health, because these meals contain more fat than meals prepared at home, and fast restaurant meals also contain percentages high in sodium and saturated fat (Ahmed et al. 2011).

Diversifying food consumption means eating different kinds of food with different ingredients so you don't have to stick to just one type. Food diversification helps meet the individual's nutrient needs, including carbohydrates, proteins, fats, vitamins, minerals, and water for energy production, growth, repair of damaged tissues, and regulation of biochemical reactions within the body. It is generally recommended to limit food and beverages that are high in calories, fat, sugar or salt to reduce the risk of chronic diseases such as obesity, type 2 diabetes, heart disease, some types of cancer and osteoporosis. Also, one type of food does not contain the necessary value, so it is necessary to diversify the foods (Wang et al. 2016).

## 2 Consumption Patterns of Saudi People

The Kingdom of Saudi Arabia is one of the largest countries in the Middle East and the most diverse in terrain. The diversity of the environment has led to the diversity of foods. There are also many who have come for Hajj and have brought their cultures and their foods with them. From this point of view, foods varied in the regions of Saudi Arabia, each according to what suits him (Arafat 2022).

The research carried by Bawazeer et al. (2021) reported five distinct dietary patterns in Saudi Arabia, including sugary, starchy, date-and-coffee, traditional, healthful, and protein. According to their findings, sweets are widely consumed, starch patterns are more common among men, and healthy eating habits are more common among older, educated men. Reducing the number of meals and snacks was likewise linked to the coffee pattern, while the traditional pattern was related to married men.

The traditional Saudi breakfast is very simple. It might consist of dates and coffee or bread with cheese—but dates and coffee can be enjoyed throughout the day. Some Saudi traditional dishes for breakfast are white bread (mafrood), roll white (samoli), white toast (tamees), bakery biscuit bread, fateer, shaborah white, whole bran cereals and breakfast cereals (Bawazeer et al. 2021). Breakfast is one of the basic meals that must be taken care of as it provides the body with energy and activity throughout the day. There are many popular Saudi breakfast foods that differ in their ingredients, but they meet with their health benefits and distinctive flavor, and the way they are prepared may differ from one region to another depending on the inherited habits in the area. Figure 1 shows a group of Saudi dishes that are popular for breakfast in Saudi Arabia.

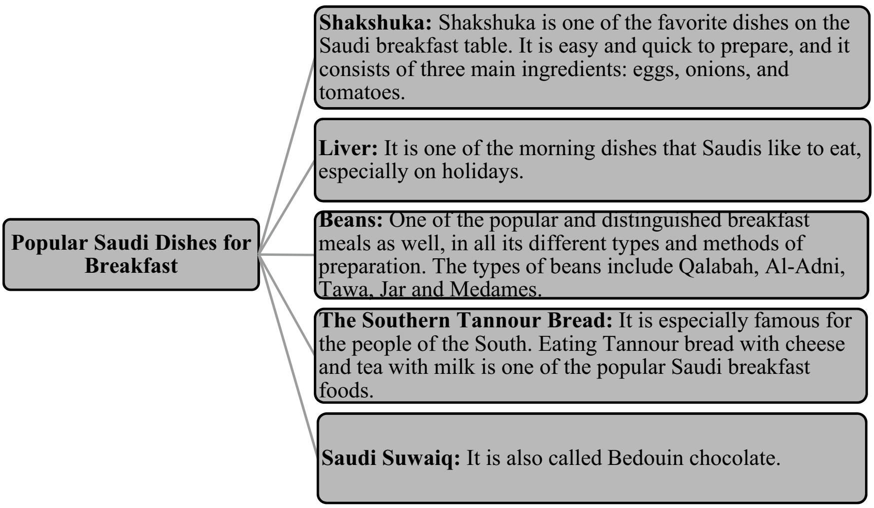


**Fig. 1** Popular Saudi dishes for breakfast in Saudi Arabia. Figure was prepared by the third author

Saudi Suwaiq is one of the famous breakfast dishes that is also called Bedouin chocolate. Suwaiq can be served as a breakfast meal or as a Saudi dessert dish. Barley is used to prepare the Suwaiq before it is ripe, with the addition of ghee on it and then dipping the dates in it, so that the Saudi Suwaiq becomes an integrated meal served on Saudi breakfast. Saudi disc (Algurs): It is one of the popular breakfast meals in the Kingdom of Saudi Arabia, and its preparation is completed from flour, and then the disc is settled in hot coals and placed under the soil. After it is ripe, the tablet is taken with milk in the morning to become an ideal healthy meal in the morning, and it can also be taken with date water.

Lunch is traditionally the main meal of the day in KSA, and almost always includes a rice dish, such as kabsa (Fig. 2), which is considered the national dish of Saudi Arabia. Delicious rice is topped with grilled chicken, meat, or even fish, and tomato and chili sauce is often served as a side dish, with a simple chopped salad. In contemporary homes, dinner is served late and is a lighter meal, often sandwiches, a Western-style dish or a hearty soup. As a Muslim country, alcohol is not served in Saudi Arabia, but this does not limit the number of drinks available in the country. It includes some fresh juices—everything from hibiscus to orange and mango—and non-alcoholic juice cocktails, as well as coffee and all kinds of tea (www.alarabiya.net).

**Fig. 2** Kabsa is the most famous Saudi food. *Source* https://commons.wikimedia.org

## 3 Saudi Food According to the Regions

The fact that the Kingdom of Saudi Arabia is one of the largest countries in the Middle East and includes a great diversity of terrain within its territory, this diversity resulting from the expansion of the area was reflected in the presence of a number of dialects belonging to each region and region, and also led to the diversity of cultures in the Kingdom, and the most prominent thing that was reflected in this difference is Saudi cuisine, as there are a large number of Saudi popular dishes that are famous for each region (DeNicola et al. 2015). There are Saudi Najd popular dishes that are distinguished by the people of the Najd region, in addition to southern Saudi popular dishes that are distinguished by the people of the south, as well as the Al-Ahsa and Hijazi cuisine. Moreover, the Kingdom of Saudi Arabia has a heritage full of civilization and traditions that extended to various aspects of the social life of the Saudi people, which all families have been keen to pass on from generation to generation so that it remains alive in their hearts. These aspects were, for example, in addition to the traditional food in the Kingdom and the famous Saudi popular dishes, Saudi food was not confined to the Kingdom only, but was able to affect many of the neighboring countries of the Kingdom, and even the peoples of the neighboring regions completely who were charmed by the delicious Saudi traditional food (Greco 2022).

There are many Saudi popular dishes that are famous for all the neighboring Arab countries, but there may be a slight difference in the way they are prepared and served, and most of these dishes consist mainly of rice and meat. The common Saudi popular dishes are illustrated on Fig. 3.

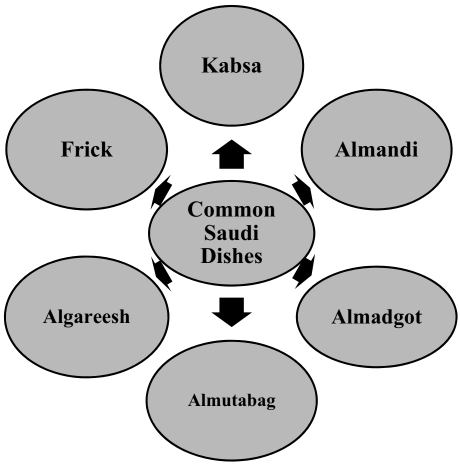


**Fig. 3** Common dishes for lunch in Saudi Arabia. Figure was prepared by the third author

## 4 What Distinguishes Traditional Saudi Food in General?

The traditional Saudi food, whether old or newly developed, is characterized by its special charming taste that a person does not forget when trying it, and the secret behind that is that Saudi food and Saudi cuisine still preserves its heritage and heritage from the ancestors, where the Saudis are proud of their traditional food inherited through centuries. The traditional Saudi breakfast is very simple consisting of dates and coffee or bread with cheese—but dates and coffee can be enjoyed throughout the day. Traditional lunch is the main meal of the day, and almost always includes a rice dish, such as kabsa (Fig. 3), which is considered the national dish of Saudi Arabia. Kabsa is generously spiced as the delicious rice is topped with grilled chicken, meat or even fish, and tomato and chili sauce is often served as a side dish, with a simple chopped salad. In contemporary homes, dinner is served later and is a lighter meal, often sandwiches, a Western-style dish or a hearty soup (Swanson 1996).

## 5 Important Ingredients in Saudi Cuisine

As we mentioned earlier, there is a great diversity in kitchens and cultures within the Kingdom of Saudi Arabia, but they all agree with the authentic delicious taste, and they agree with the necessity of the presence and use of a group of ingredients, whether in Saudi food or in Saudi sweets, and these ingredients are what made Saudi dishes unique wherever you are. The following are the ingredients that all regions in the Kingdom agree to use when preparing foods:

- Excessive use of dates and Saudi Arabian coffee.
- Honey is also used in many popular Saudi dishes.
- Using municipal ghee to add a distinctive flavor to foods.
- Great dependence on meat, as there are a very large number of popular Saudi dishes that depend mainly on meat.
- Rice is included in the preparation of many Saudi popular dishes. The consumption rate reached nearly 80% of the market consumption in all Gulf countries, meaning that Saudi consumption exceeds one million and two hundred thousand tons annually, with an average of 48 kg of rice per person annually (Assad 2007).
- Use their own Saudi spices and seasonings.

## 6 Saudi Traditional Dishes

Saudi Arabia's food diversity resulted in the presence of a number of dialects belonging to each region, and it also led to the diversity of cultures in the Kingdom. The most prominent thing that was reflected in this difference was Saudi cuisine, as there are a large number of popular Saudi dishes that each region is famous for.

## *6.1 The Most Famous Dishes of the Northern and Central Regions*

The northern regions include the cities of Arar, Rafha, Al-Turaif, and Al-Aweqiliya, and the central region includes the two largest cities, namely the city of Riyadh and the city of Al-Qassim, as well as other cities such as Al-Kharj, Al-Ghat, Wadi Al-Dawasir, and other regions, and we will mention here the most famous dishes.

### 6.1.1 Almufatah

Each of the peoples of the earth has its own cultural, social, and nutritional customs and traditions, which inevitably change according to its economic and social status. Among those customs are the dietary behaviors that parents pass on to their children and honoring the stars of society and thought leaders with their guests. In Saudi society, one of those eating habits is fatty meals, and the most famous of these meals is almufatah, which is cooking a whole lamb with rice, where white rice is cooked with lamb soup, and it is a meal that spreads in wedding invitations, when guests come, honoring friends, mutual consent between people, and strengthening kinship ties between families when they meet. Saudi food is distinguished by its delicious and distinctive taste, and it also helps to feel warm and full-on cold days, so many women are keen to learn to cook some famous foods, including the Saudi mufatah, which is one of the Saudi foods associated with banquets and large weddings. It is traditionally prepared with whole lamb that is not cut into parts and rice with spices. Lamb flesh contains all nine necessary amino acids the body needs for growth and maintenance, as well as numerous vitamins and minerals. So Saudi mufatah is an ideal component of a healthy diet. When muscular tissue needs to be built up or regenerated, eating meat promotes optimal nutrition. As a result, eating lamb may be especially useful for bodybuilders, athletes recovering from injury, and those healing from surgery (https://www.healthline.com; Ahmad et al. 2018).

### 6.1.2 Precautions for Eating Too Much Saudi Mufatah

Saudi mufatah is considered a fatty meal and is well known that two hours after eating a fatty meal, triglycerides double and are the first to increase in the blood; they pose a threat because they produce chronic inflammation in the lining of the arteries, which in turn leads to the deposition of cholesterol on the artery wall to repair the tiny tears caused by the inflammation. Sugar levels also increase after a fatty meal, which is unhealthy. Despite a threefold increase in insulin, the rise in fatty acids in the blood reduces the sensitivity of the body's cells to insulin, leading to a spike in blood sugar (Cerletti et al. 2015). As a result, it is important to avoid eating too many fatty meals, but rather all fatty foods, and to avoid purchasing fatty meats (Fig. 4).

**Fig. 4** Almufatah (Mandi) is the most famous Saudi northern region food. *Source* https://www.istockphoto.com/photo/meat-mandi-traditional-arabic-rice-food-gm617562528-107260435

## *6.2 Popular Saudi Southern Region Dishes*

The southern region in the Kingdom of Saudi Arabia includes the following provinces: Abha, Al-Baha, Najran, and Jizan. These provinces are distinguished by their delicious traditional dishes, and most of the dishes are foods with benefits and high nutritional value, as they are characterized by the presence of many the famous sweets, most of which depend on dates and honey as their main ingredient (El-Juhany and Aref 2013).

### 6.2.1 Popular Saudi Najd Dishes

The Najd region includes many cities and governorates within it, but it is mainly represented by the following regions: Riyadh, Al-Qassim, the Hail region, the eastern parts of the Makkah region, and the eastern Najd regions. The area is famous for its popular foods and sweets. The most famous Najd dishes are Margoog, which is a meal consisting of wheat dough and meat; Gababyet, which is prepared from wheat flour dough that is cut into small pieces the size of an egg, flattened by hand to become circular, and thrown into a pot filled with a mixture of vegetables and meat; and finally, Jareesh, which is a popular Saudi food famous in the Najd region and made from wheat (https://www.visitsaudi.com).

### 6.2.2 Popular Saudi Al-Baha Dishes

Popular dishes in Saudi Arabia differ from one city to another, according to the special traditions, customs, and folklore of each region. The Al-Baha region is characterized by many popular foods that include many useful and varied nutrients that are full of vitamins, and these foods usually adorn the dining tables on all public and private. The popular food in Al-Baha is mostly based on wheat, as well as some other types of grains such as barley, millet, corn, and red sorghum (duksa). With the advent of winter and the rainy and cold weather, popular dishes topped the list of foods of the people of Al-Baha, where residents of southwestern Saudi Arabia resort to eating them in search of warmth. The most popular dishes in Al-Baha are Aseeda, Aish and Areka, as well as Daghabis and Fattah.

Daghabis

It is one of the most famous foods known in the Al-Baha region. It is a dough made of wheat flour. It is cut to the size of a fist or a little larger. Then it is shaped in circular shapes and placed in a pot of boiling water with meat and broth. On wedding occasions, it is made in large sizes. As a form of hospitality.

Al-Muqnaah Bread

It is made from wheat flour, kneaded with water, then a thin rock of thickness is brought, heated well, and covered with something similar to a plate, which is known as (mashhaf). A quiet fire is lit until it is cooked, and it is customary for the people to compete to make the largest bread as a kind of honoring the guests, which is what is known as the largest loaf in the world.

Porridge

It is one of the most popular foods, especially in the southern part, and it is made of (types of ground grains, yellow and white corn, and millet), and then it is stirred using a stick at a simple speed until it is cooked with a certain viscosity, and it is usual to eat that porridge with broth, meat, ghee, and honey.

Alsuaiga

It is made from barley that is not fully ripe, as it is harvested before full maturity and cooked in stalks using a large saucepan. After full maturity, it is extracted and spread out under the sunlight until it dries, and then it is pounded well using a thick stick called (the stump). And then the grains are extracted from the spikes and impurities through the use of a sieve and sieve, and after the final filtration, it is ground using a mill, and then it is ready to be used in making porridge, which is served on a cup of ghee in a dish made of western wood.

Al-Fariqa

It is similar to Al-Muthariyya in its components, but it differs from it in texture, as it is liquid to a large extent, and it has a special privacy, and it is used to be served to the sick and the hungry, as it is easy to digest on the stomach.

Mukhwad

It is considered one of the light doughs and it is called (Magloba) and it is also called as it must be turned on the other side, and it is placed on a sheet made of iron, and sometimes it is mixed with onions and served with all kinds of edamat.

### 6.2.3 Popular Saudi Abha Dishes

Popular food in all countries expresses the taste and popular heritage that is passed down from generation to generation. "Abha" Saudi Arabia, the capital of the administrative region of Asir and the governorates affiliated to the region, is characterized by certain foods until it collected a bouquet of famous foods that it exports to various regions of the Kingdom to express this region and its ancient civilization. Despite the similarity or difference of dishes in the region, each meal has its own flavor, which makes the visitors of Abha, an opportunity to enjoy these foods.

Haneez

It is the most popular dish among the Asir governorates, especially the Tihama region. The pieces of meat are placed in a hole built in a specific way called the mukhnad, and an intense fire is superimposed on it and the meat is placed in it in an orderly manner. The meat inside comes out good, ready to eat (LeBesco and Naccarato 2015).

Al-Arika

It is a widely popular dish in the Kingdom, it is light and easy-to-make meal that is made at any time, especially at breakfast. It is made of light dough and placed in tin on the fire until it succeeds. Then it is placed in another pot, then stirred and kneaded with a large spoon until it turns into a circular shape and is coherent. Then a hole is made in the middle and ghee is poured into it. And honey and decorate with dates.

100 g of Areca contains: 231 cal, 38 g carbohydrates, 8.0 fat g, and 5.0 g protein (https://ar.wikipedia.org/wiki).

Al-Fateer (Pies)

The dough may be from wheat, corn, millet, or barley with lentils. The dough is placed in the tanoor in a longitudinal manner after the oven has been heated for a long time with wood. It is the famous bread in the region and is served with ghee, honey and milk, especially for breakfast (https://kitchen.sayidaty.net).

## *6.3 Popular Saudi Northern Region Dishes*

Since ancient times, the inhabitants of the Arabian Peninsula have practiced traditional methods to extract food products from cattle milk, and the products extracted from dairy using traditional methods remain and are popular with the majority of the population. Among the most famous local dishes in the north are al-Mudheer, Marqouq, al-Mataziz, al-Washeeq, al-Jareesh, fattah, al-Mafrouka, al-Jamriya and Kobeba Hail. In addition to these foods, Tabuk is distinguished from the rest of the northern regions by the Mansaf, which the southern region of Jordan is famous for due to its proximity to the cities of northern Saudi Arabia. The people of Al-Jawf are also famous for the delicious Arboud bread prepared on hot coals. In the past, cooking utensils were made manually from pottery and stone, so the flavors of the dishes were more delicious and healthy, and the ladies were creative in preparing dishes by adding their own touches and increasing meals of dates, wheat, barley and corn (https://www.wafyapp.com).

### 6.3.1 Mudheer

Mudheer is known by several names such as Iqt, Jameed, and Bagel. It is a food popular with the Bedouins in different countries in the Arabian Peninsula. It consists of goat's milk, and it is one of the methods used by the Bedouins in the past to preserve excess milk for later use. Mudeer is usually preserved for a year without losing its nutritional value. Mudheer or Iqt is added to some foods such as mansaf, or it is eaten dry with dates or soup without mixing it with anything. Mudheer is eaten in its form as pieces of dried milk (Fig. 5), or water is added to it, and it is fermented to return to the form of milk. It is kept in bags until winter, and when consuming it, some of it is taken to be placed in warm water for a period of time, so that it absorbs the water and softens, and to take on the consistency of filtered milk, then it is eaten with bread or with raisins and dried figs.

Al-Madheer consists of goat's and sheep's milk. It is made by boiling it over a high heat, then lowering the heat to avoid fizzing, and continuing to boil it until its

**Fig. 5** Mudheer a small, dried tablets of sheep's or goat's milk. *Source* Mariod (2018)

volume decreases and its texture becomes thick, and it continues to stir to get the water out, but taking care not to burn the milk, and then we get a dough The pot is removed from the fire to cool, then the dough is formed in the form of small balls, which are pressed by hand, and the pieces are spread on a large tray, covered and placed in the sun for 3–4 days until they are completely dry, then they are ready to eat. Salt or sugar can be added to the milk when boiling as desired.

Mariod (2018) prepared two samples of Al-Mudheer (a traditional Saudi dairy food) enriched with 5 and 10% of roasted peanuts, respectively, and compared with unfortified one through a questionnaire conducted by panelists. The composition of the products was studied using an electron microscope and a FTIR device to know the effect of adding peanut protein to Al-Mudheer protein (casein). The results revealed that mudheer enriched with 5 and 10% peanuts achieved a high degree of acceptance by panelists. FTIR results (Fig. 6) showed a clear effect of adding peanuts by 5 and 10% compared to the unfortified. Electron microscope images (Fig. 7) showed a clear contrast between the fortified mudheer and the non-fortified one.

### 6.3.2 Al-Mansaf

Al-Mansaf relied on combining many ingredients, such as jameed sour and salty milk, which is prepared from sheep's milk after boiling it. Yoghurt is added to it as yeast, then it is filtered so that water comes out of it and freezes, then it is cut and placed in the sun to dry, so we take jameed and rub it with water until we get liquid milk, and also from its components Shrak bread made on fire and saj. It is very light bread. Mansaf also consists of meat and rice. Jameed milk is added to the mixture

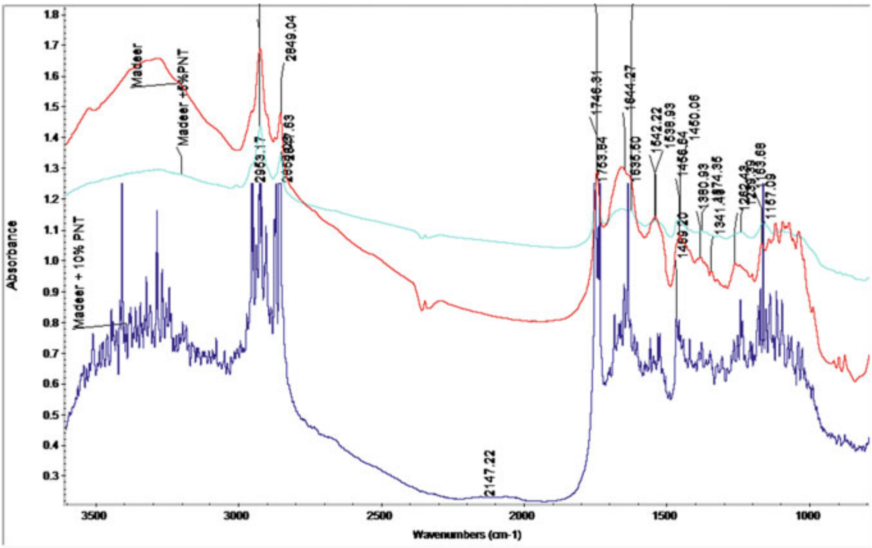


**Fig. 6** The composition of Mudheer before and after adding peanuts using FTIR. The figure shows the unfortified mudheer in green, fortified with 5% in red, and, fortified with 10% in blue. *Source* Mariod (2018)

and left on the fire to boil for an hour. Then the rice is cooked as usual and watered with broth, then the meat is spread on it, and it is decorated with pine nuts, almonds and chopped parsley. Meat, dairy, and grains are the main ingredients of mansaf. Guests are often asked to eat meat and ignore rice and bread as a show of generosity from the host. The use of grains expresses broader social and economic contexts (Wojnarowski and Williams 2020).

## *6.4 Popular Saudi Western Region Dishes*

The food culture in Saudi Arabia is very strong and vibrant, Jeddah is the main city in the western region hence the popular saying "Jeddah Ghair" which means "Jeddah is different". Travelers to Jeddah know that the locals gather in the evening around the restaurants and cafés. Their main delicious traditional foods are Maasoob, matazeez and kabsa, which are main the national dishes of Jeddah.

### 6.4.1 Masoob

One of the traditional foods in the breakfast meal, is small discs of pure wheat. If the discs are cooked in the oven, they are taken out and placed in a container of wood called a "gadah." Then an amount of honey, ghee, and banana is added to the discs,

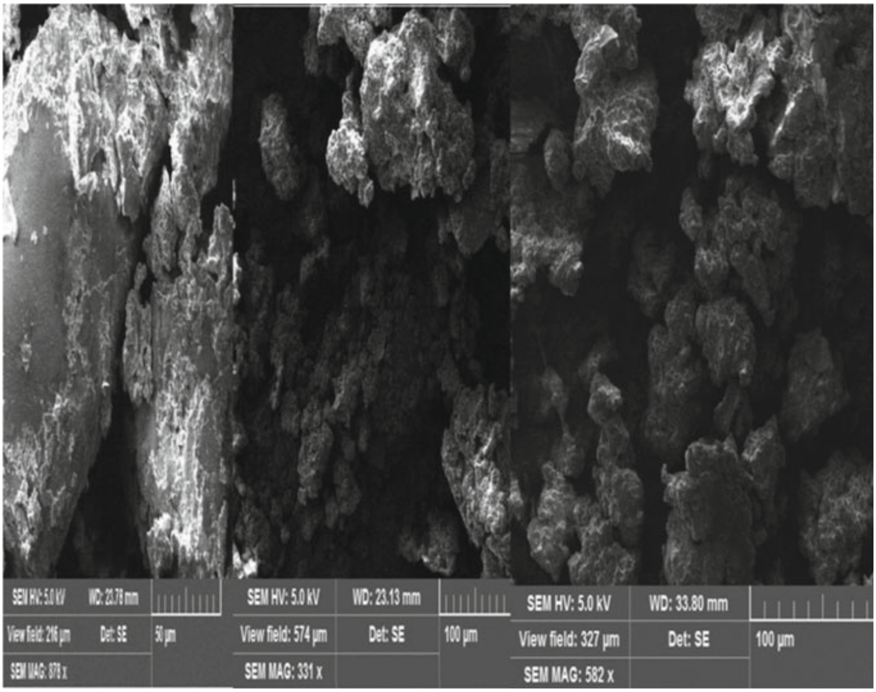


**Fig. 7** The composition of ALMUDHIR before (far left) and after adding peanuts 5% (in the middle) and 10% (on the right) under the electron microscope. *Source* Mariod (2018)

then they are pounded with a sharp instrument designated for that, and some of them He puts sugar instead of honey, and cream instead of bananas.

### 6.4.2 Sayadieh

The city of Jeddah is famous for serving Sayadiyah rice dish cooked with fish broth and distinctive local spices as a main dish. This delicious dish is served with fried or grilled seafood (such as fish, shrimp and squid). To complete the experience of enjoying seafood, add tahini salad and hot or mild vegetable salad, according to your choice. One of the customs of the people of Jeddah is the meeting of the family—which may extend to more than three generations and consists of grandparents, children and grandchildren—for lunch or dinner on Friday of every week, exchanging stories about the delicious Sayadiyah dish. The residents of Jeddah are keen to adhere to their inherited customs and traditions through their hospitality, generosity, and love for serving different dishes. They start with serving fish soup and fish salad, with fish pies, and then cooked fish and baked fish with tamarind sauce and spices. The

Fish Hospitality Festival ends with the Sayadiyah dish, and it is considered one of the main and very famous dishes in the Jeddah community (Imad and Djalal-Eddine 2020).

### 6.4.3 Al-Khawadah

Al-Khwadah is a popular food that the Bedouins were famous for in the past, and it is called Bedouin chocolate, where an intimate relationship arose between Al-Khawadah and the Bedouin of Hijazi a long time ago. It contains millet flour and municipal ghee.

The finest types of millet in Saudi Arabia are those that are grown in the Badan (is a village in the Hijaz). It is also widely cultivated in the Jizan region. Khawadha is prepared in several ways; But the most famous of them is mixing millet flour with local ghee and serving it with dates and coffee.

Product development plays an important role in the success of the main product, in order to obtain a new product that has a good flavor, distinctive color, desirable texture, and good acceptance that meets the desires of consumers. From this point of view, the khawada product was developed, which is a popular food that contains millet flour and municipal ghee.

In 2017, Mariod conducted a study that aimed to improve the waffle by improving the flavor, color and texture and thus improving the general acceptance by adding olive oil or black seed. The results of the study showed that the addition of olive oil at a rate of 1 and 2% won the satisfaction of the panelists in terms of flavour, color, texture and general acceptance, while the addition of black seed at a rate of 1 and 2% did not gain the satisfaction of the panelists in terms of flavor, color, texture and general acceptance. Mariod (2017) recommended the need to pay attention to the development of the khawadha product by adding olive oil at a rate of 1 and 2% because of its good flavor, distinctive color, desired texture and good general acceptance, and conducting other studies to increase the proportions of black seed to the khawadha product to give good flavor, distinctive color and desirable texture and good general acceptance (Table 1).

## 7 Conclusion

The Kingdom of Saudi Arabia is rich in ancient customs, traditions, and legacies, which made it a distinct country with its culture and heritage from other countries, and family bonding and family gathering on all occasions had a great impact in preserving Saudi popular dishes to this day, this was all the information we have about Saudi folk dishes and their differences from one region to another. In recent years, interest in the Kingdom has emerged as a global tourist destination, and thus the market in the field of food has become increasingly attractive, and interest has emerged in brands of international restaurants and foods, along with interest in and a

**Table 1** The results of the hedonic test (%) for the panelists in terms acceptance

| Acceptance | Traditional khawadha | Addition of 1% olive oil | Addition of 2% olive oil | Addition of 1% nigella seeds | Addition of 2% nigella seeds |
|---|---|---|---|---|---|
| Like extremely | 12.86 | 14.29 | 12.86 | – | – |
| Like very much | 17.57 | 17.14 | 15.71 | 5.71 | – |
| Like moderately | 11.43 | 32.86 | 32.86 | 5.71 | 2.86 |
| Like slightly | 10.0 | 22.86 | 21.43% | 7.14 | 8.57 |
| Neither like nor dislike | – | – | – | – | – |
| Dislike slightly | 18.57 | 12.86 | 5.71 | 28.57 | 18.57 |
| Dislike moderately | 15.71 | – | 7.14 | 21.43 | 28.57 |
| Dislike very much | 12.86 | – | 4.29 | | 24.29 |
| Dislike extremely | – | – | – | 15.71 | 17.14 |

*Source* Mariod (2017)

return to traditional Saudi food, and consumers have become They are increasingly selective in their desire to know and try more meals, and the culture of knowing the ingredients of meals has spread, especially for those who offer healthy options using local sources, which gives great hope that local meals will compete with international ones or at least take their place among them.

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# Chapter 14
# Contribution of Hassawi Rice to Food and Nutritional Security in Saudi Arabia

**Muneera Q. Al-Mssallem, Jameel M. Al-Khayri, Fatima M. Alessa, and Hayat Z. Al-Shalan**

**Abstract** Rice (*Oryza sativa* L.) is an essential agricultural species that plays a vital role in fulfilling the nutritional needs of over 60% of the world's population. It is well-documented that the Al-Ahsa oasis in the Eastern region of Saudi Arabia is the birthplace of Hassawi rice (*Oryza sativa* L. cv. Hassawi), which has been cultivated there for hundreds of years. For the past seven decades, Hassawi rice has been fundamental in food and nutritional security in Al-Ahsa oasis and surrounding regions, as it was considered a stable food alongside dates. However, currently, there has been a reduction in Hassawi rice production, and it is mainly served during special occasions. Despite the fact that Hassawi rice has a lower content of total carbohydrates than other rice varieties, it contains higher levels of protein, dietary fiber, calcium, phosphorus, iron, thiamine, and antioxidants than white basmati rice. For instance, 100 g of uncooked Hassawi rice provides an average of 25% of daily recommended dietary allowance of dietary fiber compared to only 4% from white Basmati rice. Its high nutritional values and the nature of its carbohydrates make Hassawi rice the best option for people with diabetes and those who want to control their weight rather than maintain their health. This chapter emphasizes the originality of Hassawi rice, its cultivation, production, significance in food and nutritional security, nutritional value, and health benefits.

M. Q. Al-Mssallem (✉) · F. M. Alessa
Department of Food and Nutritional Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: mmssallem@kfu.edu.sa

F. M. Alessa
e-mail: falissa@kfu.edu.sa

J. M. Al-Khayri
Department of Agricultural Biotechnology, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: jkhayri@kfu.edu.sa

H. Z. Al-Shalan
Department of Human Nutrition, College of Food and Agricultural Sciences, King Saud University, Riyadh 11451, Saudi Arabia
e-mail: hayatalshalan@gmail.com



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**Keywords** Abiotic stress · Cultivation · Environmental conditions · Food security · Hassawi rice · Nutritional security · Socioeconomic values

## 1 Introduction

Saudi Arabia is characterized by vast areas of sand dunes, some tall mountains, islands, coasts, and fertile oases. The largest and most famous oasis in Saudi Arabia is Al-Ahsa Oasis, which has plenty of environmental elements that meet the requirements for cultivating and growing a special type of rice variety known as Hassawi rice (*Oryza sativa* L. cv. Hassawi). Hassawi rice is the most distinctive product in Al-Ahsa Oasis (Al-Khayri and Al-Bahrany 2002). It is believed that Hassawi rice originated from the Indonesian variety Peta (Zhang et al. 2012) and has been cultivated in Al-Ahsa for hundreds of years (Al-Elawy 1976; Chang et al. 1981). The cultivation of Hassawi rice is even considered a milestone for some villages in Al-Ahsa, such as Shiraa Al-Ayouni, Shiraa Al-Batalia, Shiraa Al-Shu'bah, Al-Qurain, and Al-Julaijlah (see Fig. 1). This chapter primarily discusses the historical significance of cultivating and producing Hassawi rice, as well as the factors that influence its adaptation. It highlights the importance of Hassawi rice in securing food and meeting nutritional requirements.

**Fig. 1** An instrument endowment for Hassawi rice issued in 1036 AH (1902 AD), more than 4 centuries ago. *Source* Pests and Plant Diseases Unit, College of Agricultural and Food Sciences, King Faisal University

### 1.1 Cultivation and Production of Hassawi Rice

The cultivation and production of Hassawi rice require specific conditions in terms of agricultural soil and appropriate climate. Al-Ahsa, where soil fertility and dark grey-brown loam with moderate acidity and high temperature strongly support the growth of Hassawi rice, is the origin of this type of rice (Chang et al. 1981). Hassawi rice is traditionally planted manually by hand in basins called Dhwahi, edged usually by date palm trees. The first Hassawi rice seedlings are obtained after sowing seeds in well-prepared, fertile soil during late May to early June. The second stage of cultivation, called Sanayah, occurs in July and August. It begins with the transfer of seedlings into Dhwahi, and soaking them in water for eight to fourteen days. The seedlings are usually irrigated once a week for 40 days. After that, irrigation is suspended for 10 days, and then the growth of seedlings is usually irrigated as normal until they are harvested between September and October of each year. The harvest time of Hassawi rice is called Al-Wasmi. This traditional cultivation process has been inherited over generations (Figs. 2 and 3). It is a labor-intensive process that takes about 5–6 months and just needs to be irrigated with plenty of water for the first 45 days. Compared to other varieties of rice, Hassawi rice requires less water for irrigation in general, due to its adaptability to high temperatures, soil salinity, and drought (Al-Jabr 1984; Zhang et al. 2012). The best time of cultivation for Hassawi rice is from late May to early June, and its growth period lasts for 160–180 days. This agricultural practice in Al-Ahsa oasis is facilitated by the availability of abundant fresh water from artesian or dug wells, and the traditional irrigation system there is based on flood irrigation. Indeed, the ground water sources are characterized by high salinity and high sodium hazard. In the past, manual or animal-powered devices were used to raise water from wells or bring water from distant groundwater sources through open ducts (Chang et al. 1981). However, nowadays mechanical pumping of groundwater resources is applied for irrigation.

The cultivation of Hassawi rice produces a large amount of grains per spike, with each spike containing approximately 80 grains. However, there is some annual variation in production. In fact, the production of Hassawi rice has declined (as shown in Fig. 4) due to several factors, including the depletion of groundwater and the reduction of arable land (Al-Jabr 1984). Moreover, many young farmers are not interested in cultivating Hassawi rice because the process requires a lot of hard work and full attention, as well as teamwork.

### 1.2 General Uses of Hassawi Rice

Hassawi rice is typically used in a traditional Saudi Arabian dish called Kabsa (Fig. 5), which is served with cooked vegetables and meat such as lamb, fish, or chicken (Al-Mssallem 2018). Research has shown that Hassawi rice has greater nutritional value compared to white rice (see Sect. 4), making it a recommended dietary option for


**Fig. 2** To prepare Dhwahi, seeds are sown in late May or early June and covered with a layer of mud. The seeds are then watered to promote germination and left to grow for a period of 40–45 days. Another method involves immersing the Dhwahi with water (See **b**) to prepare for planting seedlings transferred from Dhwahi **a**. This process occurs in July and August (Sanaya), and the seedlings are left in water for 40 days before being watered normally until harvest time in late September to October (Alwasmi). Photos by AbdulAziz A. Al-Mssallem

women during the postpartum period (Al-Mssallem et al. 2011). Another popular Saudi Arabian dish, Saleeqah, is prepared similarly to Kabsa but with the addition of chard known as "Silq" (*Beta vulgaris* L.). Additionally, Hassawi rice is often used in dishes such as stuffed grape leaves as a substitute for Snow White rice, and is also being used more recently to produce rice flour for cookies and crackers.

## 2 Hassawi Rice Importance and Utilization

### *2.1 Socio-economic Values*

In the past, Hassawi rice played a significant role in strengthening commercial relationships among the people in the Arabian Peninsula and neighboring countries. It was actually the second most produced crop in Al-Ahsa, after dates (Al-Jabr 1984). Even though the socioeconomic situation has rapidly and fundamentally changed in the last eight decades, cultivating Hassawi rice is still a traditional agricultural practice that has been passed down from ancestors and will continue to be passed down to descendants. It holds a fundamental place in the hearts of Hassawi farmers towards society. Agricultural practices of Hassawi rice were not only a means of livelihood for the farmer and his family, but also represented generosity and hospitality, and was proof of cooperation, brotherhood, love, and solidarity. The yield of Hassawi rice ensured the daily needs of the farmer and his family as well as being distributed among their relatives and neighbors. A document dating back to 820 AH (1417 AD)

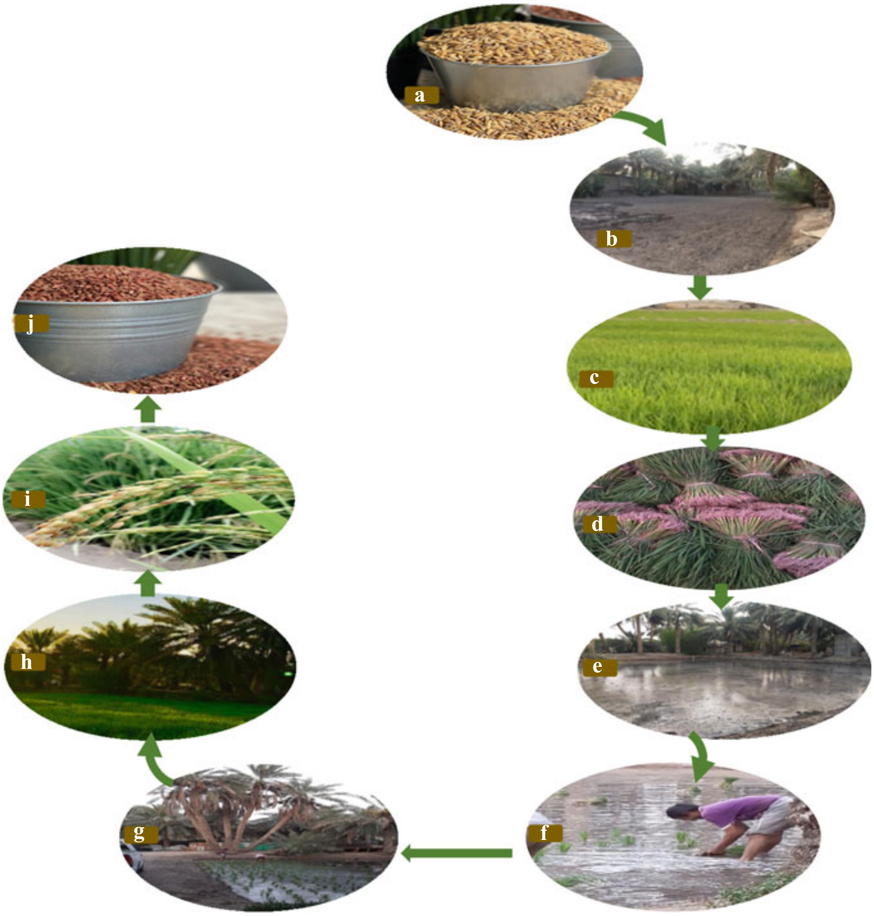


**Fig. 3** Cultivation and production of Hassawi rice process. Hassawi rice seeds (shelb) are ready for planting (**a**). Basins 1 (Dhwahi) are prepared for sowing Hassawi rice seeds (**b**). Growth of seeds and form seedlings during 40–45 days (**c**). Seedlings are ready for Sanayah action (**d**). Basins 2 (Dhwahi) are prepared for planting seedlings (**e**). Planting seedlings (Sanayah) in prepared Dhwahi (**f**). Seedlings are soaked for 40–45 days (**g**). Seedlings growth (**h**). Rice spikes (**i**). Hassawi Rice grains are ready for consumer (**j**). Photos by AbdulAziz A. Al-Mssallem & Shareefa Q. Al-Mssallem

was found which endowed the names of Hassawi rice farms to the poor for their benefit (Al-Hussain 2019).

## 2.2 *Research Advances*

Hassawi rice has caught the interest of scientific researchers due to its ability to withstand the harsh environmental conditions of Al-Ahsa oasis, such as salinity,

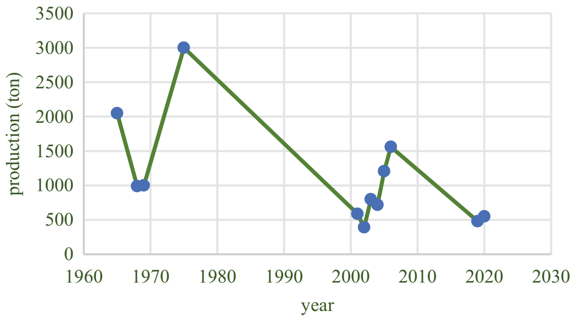


**Fig. 4** The fluctuation in the production of Hassawi rice. *Source* Al-Jabr (1984), Al-Gazal (2021)


**Fig. 5** Uncooked Hassawi rice Shelb [left, (**a**)] and grains [right, (**a**)]. Cooked Hassawi rice served into Kabsa (**b**). Photos by Shareefa Q. Al-Mssallem

drought, and extreme hot temperatures. However, it does have some unfavorable characteristics, such as sensitivity to day length, delayed maturation, and susceptibility to lodging (Chang et al. 1981). To overcome these undesirable traits, a breeding program was carried out between the Republic of China and Saudi Arabia, resulting in the production of Hassawi-1 and Hassawi-2 (CATM 1985).

Several scientific studies have been conducted on Hassawi rice by researchers from King Faisal University since the 1990s. One of the initial works focused on the storage protein of Hassawi rice (Al-Mssallem and Al-Mssallem 1997). Other studies have looked at in vitro regeneration (Al-Khayri and Al-Bahrany 2000), fatty acid analysis (Al-Bahrany 2002), response of cell cultures to water stress (Al-Khayri and Al-Bahrany 2002), effect of fertilizer nutrients on yield (Al-Gusaibi 2004), nutritional composition (Hadid and Elsheikh 2012; Al-Mssallem et al. 2011), glycaemic and insulinaemic index values (Al-Mssallem et al. 2011), breeding (Bimpong et al. 2014), in vitro carbohydrate hydrolysis (Al-Mssallem et al. 2014), genomics (Zhang et al. 2012), antioxidants activity (Al-Mssallem and Alqurashi 2021), and phytochemical components (El-Beltagi et al. 2022). It is important to continue conducting scientific studies on Hassawi rice to emphasize its role in improving food security and environmental sustainability.

The College of Agriculture and Food Sciences at KFU is interested in advancing scientific progress on Hassawi rice. Therefore, a Scientific Team of Hassawi Rice Researchers was established in May 2022. One of the team's most important tasks is to motivate and encourage researchers to conduct scientific work on Hassawi rice, such as clinical studies to investigate the benefits of Hassawi rice in protecting or treating chronic health conditions, biotechnological research to adapt the genes of Hassawi rice in order to improve production characteristics and increase nutritional value, manufacturing Hassawi rice, creating a database of annual production statistics of Hassawi rice, studying the economics of production, marketing, consumption, and consumer demand. As a result, some proposed research projects have been submitted to be considered for possible funds (Table 1).

## 3 Hassawi Rice Significance in Food Security

### *3.1 Historical Overview*

Hassawi rice, also known as *Oryza sativa* L. cv. Hassawi, has been cultivated for several centuries. It is well adapted to the soil salinity and hot weather conditions of Al-Ahsa oasis in Saudi Arabia (Zhang et al. 2012). For over 7 decades, Hassawi rice has been a staple food for most of the Hassawi population, second only to dates in providing daily nutritional needs. Historically, Hassawi rice production was used to provide for the needs of poor people, as far back as the fourteenth century when the Princes of Al-Ahsa endowed their Hassawi rice farms for the benefit of the poor (Al-Hussain 2019).

### *3.2 Climate Change Implications*

Climate change plays a significant role in natural resources and has a serious impact on food and nutrition security. The effects of climate change on food security can be observed through changes in food availability, accessibility, supply stability, and price volatility. In Saudi Arabia, the prevailing climate is arid, making it vulnerable

**Table 1** Some suggested forthcoming researches on Hassawi rice

| Proposed scientific research | Institution | Department | Proposed funding body |
|---|---|---|---|
| Hassawi rice biofortification to enrich micronutrients towards ensuring food and nutritional security | King Faisal University | Agricultural Biotechnology<br>Central Laboratories<br>Food Sciences and Nutrition | Deanship of Scientific Research, King Faisal University |
| Genome editing in Hassawi rice for high salinity tolerance to secure food and nutritional security in Saudi Arabia | King Faisal University | Agricultural Biotechnology<br>Central Laboratories<br>Food Sciences and Nutrition | Deanship of Scientific Research, King Faisal University |
| Genetic improvement of Hassawi rice to enhance food security in Saudi Arabia: molecular breeding for development of abiotic stress tolerance | King Faisal University | Agricultural Biotechnology<br>Central Laboratories<br>Food Sciences and Nutrition | Deanship of Scientific Research, King Faisal University |
| Morphological and molecular characterization of some genotypes of Hassawi rice | King Faisal University | Agribusiness and Consumer Sciences | Deanship of Scientific Research, King Faisal University |
| Using stochastic frontier to estimates and analysis the technical efficiency for rice production in Al Ahsa oasis, Saudi Arabia | King Faisal University | Agribusiness and Consumer Sciences<br>Agricultural Biotechnology | Deanship of Scientific Research, King Faisal University |
| Bioactive compounds of Hassawi rice and their beneficial impact on gut health | A joint project between University of Northumbria, UK and King Faisal University, SA | Department of Applied and Health Sciences, NU, UK<br>Department of Food Sciences and Nutrition | International Cooperation and Knowledge Exchange Administration, King Faisal University |

to the adverse effects of climate change. There has been a decrease in precipitation and severe droughts, leading to the severe degradation of ecosystems (Haque and Khan 2022). Assessing temperature and rainfall is considered a reliable indicator for predicting future climate change trends. In Saudi Arabia, there has been a decrease in rainfall in many areas and an increase in temperature across the country (Tarawneh and Chowdhury 2018). It has been observed that there has been a significant increase in the average temperature by 1.9 °C in the last 5 decades. This increase in temperature indicates that a one-degree Celsius increase can lower crop yield by 7–25% (Haque and Khan 2022; Zhai and Zhuang 2009).

Like other regions in Saudi Arabia, the climate in Al-Ahsa is characterized by extremely hot weather that ranges from 46 to 51 °C during the summer, and reasonably dry and cool in the winter (Alharbi and Sultan 1985; Youssef et al. 2016). Hassawi rice, like any other crop, is sensitive to fluctuations in temperature and rainfall. In fact, the hot summer weather in Al-Ahsa is considered suitable for growing Hassawi rice because of its specific climatic needs. Additionally, the fertile loam soil found in Al-Ahsa retains water for longer periods of time and is compatible with the extreme hot climate conditions. Hassawi rice is unique in the sense that, during its 5–6 month growth period, it requires generous irrigation in the first two months. It also has a high tolerance for extreme dry weather, drought, and soil salinity, making it well-suited for cultivation in the challenging agro-environmental circumstances of the Al-Ahsa oasis (Almeida et al. 2017). However, the limited rain and scarce irrigation water from underground wells restrict Hassawi rice production and cause fluctuations in its economic sustainability. Therefore, implementing a sustainable water resource management strategy is necessary.

### *3.3 Relevance to Food Security and Farmer Livelihood Protection*

Food security, as defined by the FAO, refers to a situation where all individuals have consistent access to sufficient, safe, and nutritious food that meets their dietary needs and preferences for healthy and active living at all times. Hassawi rice has played a significant role in ensuring this security for the local community's food and livelihood. Over the past 70 years, it has been grown in ample quantities to provide for the local populace and even exported to neighboring regions. Hassawi rice was a staple food for many local people after dates. Unlike other varieties, Hassawi rice can be stored for several years under dry and clean conditions. It has been documented that some Hassawi rice farms were established to benefit poor people (Al-Hussain 2019). However, the cultivation, production, and consumption of Hassawi rice has declined due to several reasons. These reasons include competition from imported rice varieties, the high demand for manual labor, and changing eating patterns (Al-Jabr 1984; Al-Mssallem 2018). Efforts are underway to improve the cultivation of Hassawi rice while also ensuring the preservation of the environment and the betterment of livelihoods. The Saudi Ministry of Culture, represented by the Culinary Arts Commission, has initiated a project to register Hassawi rice Dhwahi as a globally important agricultural heritage system (GIAHS) at FAO in the Al-Ahsa oasis. The registration of Hassawi rice Dhwahi as a GIAHS is a significant step towards preserving the continuity of its cultivation and preventing its extinction.

### 3.4 Factors Influencing Adoption

There are several factors that can influence the cultivation and production of Hassawi rice, including its high demand for irrigation water, soil salinity, drought, photoperiod sensitivity, susceptibility to lodging, and delayed maturity (Almeida et al. 2017; Chang et al. 1981; Zhang et al. 2012). Furthermore, cultivating Hassawi rice requires intensive labor and cooperative teamwork. However, some of these undesirable traits of Hassawi rice have been addressed. To improve its susceptibility to lodging, photoperiod sensitivity, and delayed maturity, two varieties—Hassawi-1 and Hassawi-2—were developed from local Hassawi rice through a breeding program carried out under the Agricultural Cooperation Agreement between the Republic of China and Saudi Arabia (Chang et al. 1981; CATM 1985). Hassawi rice possesses a unique property of being able to tolerate high levels of soil salinity, severe heat, and drought (Chang et al. 1981). For this reason, the Al-Ahsa oasis is well-suited for the growth of this variety of rice.

## 4 Hassawi Rice Significance in Nutritional Security

### 4.1 Nutritional Value and Health Benefits

Hassawi rice, like any variety of rice, is considered a source of carbohydrates (CHOs). However, its CHOs content is lower compared to other varieties of white rice (Al-Mssallem et al. 2011). Table 2 shows that Hassawi rice has higher protein, fat, non-starch polysaccharides (NSPs), mineral content (calcium, phosphorus, iron), water-soluble vitamins (thiamine, riboflavin), and phenolic compounds compared to Basmati rice (Al-Mssallem et al. 2011; Hadid and Elsheikh 2012; Al-Mssallem and Alqurashi 2021). Hassawi rice's most abundant fatty acids are linoleic, oleic, and palmitic acids. Hassawi rice's unsaturated fatty acids constitute 76% of its total fatty acids (Al-Bahrany 2002). Consuming Hassawi rice offers greater nutritional benefits than white Basmati rice. For instance, Hassawi rice provides 25% NSPs compared to Basmati rice's 4% NSPs (Table 2). As an unrefined and unprocessed crop, Hassawi rice is a good source of NSPs, minerals (e.g. calcium and iron), vitamins (e.g. thiamine), and antioxidants. Foods rich in NSPs have been shown to reduce the risk of obesity and diabetes (Al-Mssallem et al. 2011). Using Hassawi cell suspension culture, secondary metabolites can be produced on a large scale (El-Beltagi et al. 2022).

The quality of carbohydrates (CHOs) in Hassawi rice is characterized by gradual hydrolysis and slow absorption. This unique feature of its carbohydrates has been confirmed by in vitro and in vivo studies of the carbohydrates of Hassawi rice (Al-Mssallem et al. 2011, 2014). It has been found that Hassawi rice has a lower glycemic load (GL) and insulinaemic index (II) compared to white rice (Fig. 6), despite the fact that the glycemic index values of both varieties were close (Al-Mssallem et al.

**Table 2** Nutrients contents and percentage of daily value in 100 g of raw Hassawi rice and Basmati rice

| Components | Hassawi rice | % daily value | White rice | % daily value |
|---|---|---|---|---|
| Energy (calorie) | 327 | 18 | 362 | 20 |
| Total carbohydrates (g/100 g) | 66.82 | 26 | 78.68 | 30 |
| Non-starch polysaccharides (g/100 g) | 6.22 | 25 | 0.96 | 4 |
| Total protein (g/100 g) | 10.49 | 14 | 7.97 | 10 |
| Total fat (g/100 g) | 1.99 | 4 | 1.66 | 3 |
| Calcium, Ca (mg/100 g) | 12.6 | 1.05 | 5.7 | 0.5 |
| Phosphorus, P (mg/100 g) | 185 | 15 | 125 | 10 |
| Iron, Fe (mg/100 g) | 1.3 | 9 | 0.89 | 6 |
| Thiamine, B1 (mg/100 g) | 0.55 | 50 | 0.18 | 16 |

*Source* Al-Mssallem et al. (2011), Al-Mssallem and Alqurashi (2021)

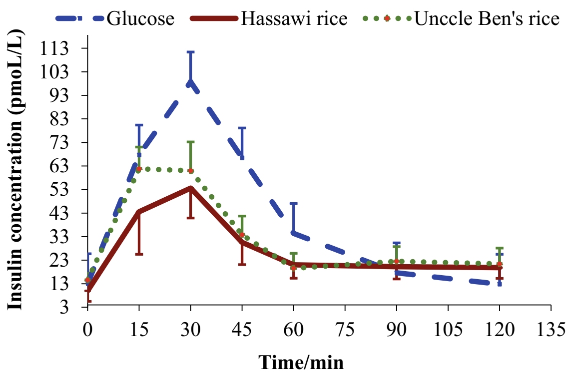


**Fig. 6** Insulinaemic index of Hassawi rice and white Uncle Ben's rice. *Source* Al-Mssallem et al. (2011)

2011; Al-Mssallem 2018). Because of the nature of its carbohydrates, low GL value, and low II value, Hassawi rice is recommended for controlling weight and blood glucose levels (Al-Mssallem 2014). Research on exploring the impact of Hassawi rice contents on microbiota and their impact on human guts is in progress. More clinical research studies on its potential health benefits are required.

## *4.2 Physico-Chemical Properties*

Hassawi rice is a type of pigmented rice that is characterized by its brown reddish color (as shown in Fig. 5a). The moisture content of both uncooked and cooked Hassawi rice is approximately 62%, according to Al-Mssallem et al. (2011). Like any variety of rice, the main chemical component in Hassawi rice is carbohydrates, with an amylose content of approximately 17.5/100 g in cooked Hassawi rice. The

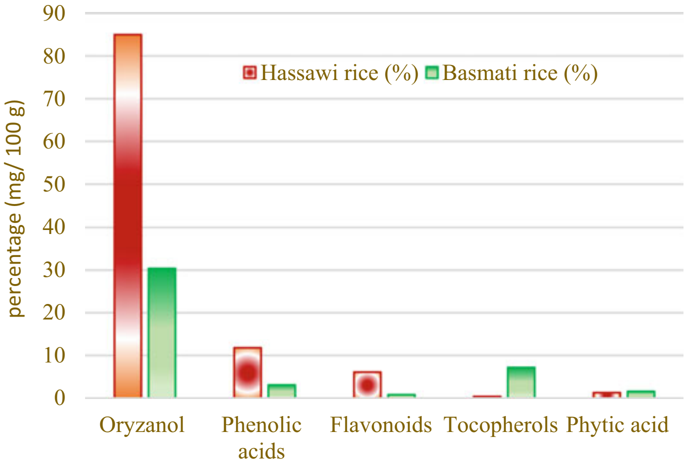


**Fig. 7** Phytochemical contents in Hassawi rice in comparison to Basmati white rice. *Source* Hadid and Elsheikh (2012), Al-Mssallem and Alqurashi (2021)

macro and micro chemical compositions of Hassawi rice are detailed in Table 2. Furthermore, bioactive compounds such as phenolic compounds, flavonoids, and anthocyanins are present in Hassawi rice (as demonstrated in Fig. 7). The main lipophilic phytochemical compound in rice is oryzanol, and it is almost three times more prevalent in Hassawi rice than in Basmati rice. These bioactive compounds act as essential antioxidants, as they have the ability to scavenge free radicals and provide protection against chronic degenerative disorders. In fact, Hassawi rice has been found to have higher antioxidant activity than Basmati rice [as reported by Hadid and Elsheikh (2012) and Al-Mssallem and Alqurashi (2021)]. Further studies are recommended to explore the quality and quantity of bioactive compounds present in Hassawi rice.

### *4.3 Relevance to Nutritional Security Strategies*

Food security is a major concern for policy makers in the Middle East, particularly in Saudi Arabia. As the country's local food production is not sufficient to meet domestic needs, the majority of food commodities are imported from other countries (Fiaz et al. 2018). In fact, around 80% of the country's food requirements are imported. Despite having the largest area among Arab countries (2,149,690 $km^2$) and a population of over 30 million, only 1.6% of Saudi Arabia's land is arable. Moreover, the country's agriculture sector consumes about 88% of its water, with the average consumption being around 24 billion $m^3$. To address this challenge, Saudi Arabia has established various intensive agricultural extension activities, including schemes, practices, universities, government bodies, and programs, aimed at increasing productivity and achieving nutritional food stability. The country's top priority should be to increase the availability of arable land to enhance crop productivity (Faridi and Sulphey 2019).

Land and water are the primary limiting factors for agricultural production. The Kingdom of Saudi Arabia is experiencing a water shortage due to several reasons, including increasing population growth, inappropriate distribution of water resources, poor water quality, low rainfall, high evaporation rates, aridity, and increasing demand for freshwater. These factors are putting additional pressure on water security and potentially affecting groundwater, which cannot withstand these circumstances. Thus, there is a high demand for an efficient and sustainable solution to manage water resources (Fiaz et al. 2018).

Recently, several potential technologies for saving land and water have been applied to meet domestic energy requirements. These include promoting traditional crops, harvesting seawater and rainwater, and utilizing greenhouse and hydroponic farming. Therefore, it is crucial to activate the role of extension agents to encourage the use of innovative agricultural technologies and increase farmers' awareness of guidelines to achieve sufficient production of dietary needs in Saudi Arabia. There are several methodologies that can be applied in Saudi Arabia to achieve national food security and expand national food manufacturing. Innovative conventional and non-conventional land and water technologies are essential for providing sustainable yields as well as conserving non-renewable resources. Conventional crops promotion is one strategy for achieving nutritional security (Fiaz et al. 2018). Additionally, hydroponic and greenhouse farming technologies have been found to be effective in producing sustainable, high-quality fruits and vegetables using nutrient-rich water under controlled conditions. The hydroponic greenhouse technique has increased vegetable production from 5 tonnes in soil fields up to 200 tonnes yearly for each planted acre. Moreover, low amounts of water (2–10%) are required for these techniques for the same crop production under soil conditions and only 3–5% of water under field conditions (Al-Karaki and Al-Hashimi 2012).

Seawater is a suitable, cost-effective technique that can be applied in desert areas. This technique involves building greenhouses in far-flung and coastal areas to use saltwater in planting food crops. The condensed freshwater resulting from seawater evaporation is utilized to grow these crops. The greenhouse creates cool air for plant cultivation through sunlight and seawater. Low humidity and the availability of seawater are ideal conditions for this technique, such as the Red Sea in Saudi Arabia. Harvesting rainwater is a beneficial technique for effectively using rainwater for lateral use. Rainwater harvesting requires effectively managing three landscape elements: the condition of soil and landscape runoff, water flow created by variations in the elevation of the landscape, and a sufficient deep soil horizon. Recently, the amount of water available has increased from 1400 to 3000 million $m^3$. King Fahad's dam, located in Wadi Bishah of Saudi Arabia, has the largest dam with a height of 103 m and a storage capacity of 325 million $m^3$ (Fiaz et al. 2018).

Biotic stresses, such as insect pests, pose a significant challenge to sustaining Hassawi rice production. They have the potential to affect up to 25% of rice production worldwide. The main insect pests that affect rice crops are stem borers (Chilo agamemnon Bles.), which can cause yield losses of over 70%. To reduce these losses, an economic, viable, and ecologically acceptable approach should be employed. Breeding for insect-resistant crop varieties is the most effective integrated pest management approach to combat stem borer infestations in rice production through a breeding program (Al-Daej et al. 2022).

## 5 Conclusions and Prospects

For hundreds of years, Hassawi rice has been grown in the Al-Ahsa oasis, increasing food and nutritional security due to its high nutritional value when compared to imported rice. However, the challenges of climate change mean that research must focus on improving this landrace rice to ensure that it can continue to be cultivated sustainably. Modern breeding technologies offer opportunities to improve specific traits, with the aim of increasing productivity and enhancing nutritional content. Given the scarcity of water in the region, it is vitally important to develop resilience to water stress, which is a major abiotic stress factor. In addition, research must prioritize developing tolerance to biotic stress to achieve sustainability. Hassawi rice is known for its numerous medicinal properties, and there is potential to produce pharmaceutical compounds at a commercial scale, adding significant value.

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# Chapter 15
# Role of Date Palm to Food and Nutritional Security in Saudi Arabia

**Muneera Q. Al-Mssallem, Jameel M. Al-Khayri, Budour A. Alghamdi, Nahaa M. Alotaibi, Modhi O. Alotaibi, Rahmah N. Al-Qthanin, and Hayat Z. Al-Shalan**

**Abstract** It is true that date palm (*Phoenix dactylifera L.*) holds a significant position in the life of Muslims, especially those of Arab culture, due to its cultural, religious, livelihood, and economic significance. It is an essential part of the diet and culture of Saudi Arabia, where the nutritious date palm fruits are typically eaten at the Rutab and Tamer stages. These fruits have been a staple food for Arabs since ancient times and have played a crucial role in improving food and nutritional security and economic circumstances. The functional characteristics and nutritional content of date palm fruits contribute significantly to improving general human health. Consuming an average of seven date fruits by adults can provide approximately 13%, 20%, and 25% of the recommended dietary allowance for energy, dietary fiber, and potassium, respectively. In addition to its nutrient-rich fruits, the date palm is also considered a significant natural renewable resource for many by-products, handicrafts, and architecture. The date palm contributes substantially to the socioeconomic development

M. Q. Al-Mssallem (✉)
Department of Food and Nutritional Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: mmssallem@kfu.edu.sa

J. M. Al-Khayri
Department of Agricultural Biotechnology, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: jkhayri@kfu.edu.sa

B. A. Alghamdi
National Research and Development Center for Sustainable Agriculture (Estidamah), Riyadh Techno Valley, King Saud University, Riyadh 12373, Saudi Arabia
e-mail: alghamdib@estidamah.gov.sa

N. M. Alotaibi · M. O. Alotaibi
Department of Biology, College of Sciences, Princess Nourah Bint Abdulrahman University, Riyadh 11671, Saudi Arabia
e-mail: namialotaibi@pnu.edu.sa

M. O. Alotaibi
e-mail: mouotaebe@pnu.edu.sa

 
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of nations, particularly Saudi Arabia. Ensuring food security has become a challenge that countries and organizations must address with possible solutions through increasing the cultivation of crops that are rich in nutrients and hold significant commercial values. The high-nutrient fruits of the date palm are a valuable contribution to achieving food and nutritional security at both local and global levels. The primary goal of this chapter is to highlight the research that has been conducted on date palm and its fruits in terms of their roles in food and nutritional security in Saudi Arabia's diet, culture, life, economy, and society.

**Keywords** Biodiversity · Cell culture · Date palm · Food security · Genomics · Nutritional security · Saudi Arabia

## 1 Introduction

### *1.1 Historical Overview and Distribution*

Date palms (*Phoenix dactylifera* L.) are the oldest cultivated trees worldwide and are a symbol of arid and semi-arid regions in the Middle East. The fruit of the date palm has been consumed for millennia and was once considered a staple food for Arabs during ancient times, though their dietary habits have since shifted to incorporate other foods. Date palms hold historical significance in terms of livelihood, culture, environment, income, and religion. Archaeobotanical studies and textual evidence indicate that the date palm originated in the Arab Gulf region and ancient Mesopotamia before its global cultivation spread to other parts including South and North America, southern Europe, Asia, and Australia (Tengberg 2012).

It is a fact that date palm fruit matures and ripens in dry and hot weather conditions, making it well-suited for arid and semi-arid climates (Manickavasagan et al. 2012; Tengberg 2012). Asia and Northern Africa are the primary regions for date production, with minor output from scattered regions of North America and South Europe (Abul-Soad et al. 2017). New regions in the Western Hemisphere have also

R. N. Al-Qthanin
Department of Biology, College of Sciences, King Khalid University, Abha 61421, Saudi Arabia

Prince Sultan Bin-Abdul-Aziz Center for Environment and Tourism Studies and Researches, King Khalid University, Abha 61421, Saudi Arabia

R. N. Al-Qthanin
e-mail: rngerse@kku.edu.sa

H. Z. Al-Shalan
Department of Human Nutrition, College of Food and Agricultural Sciences, King Saud University, Riyadh 11451, Saudi Arabia
e-mail: hayatalshalan@gmail.com

recently begun cultivating date palms, but they remain a more limited production area (Krueger 2021).

## 1.2 Biodiversity

The date palm is considered an essential element of biodiversity due to its ability to adapt to harsh climate conditions. Date palm species have a high level of outbreeding behavior, which has led to massive genetic diversity. Reports indicated there are over 3000 known varieties of date palm, approximately 450 of those varieties exist in Saudi Arabia (Al-Redhaiman 2014; Al-Khalifah et al. 2012). However, there is ambiguity in listing cultivars based on local names due to the diversity within the species. For example, one name may refer to different cultivars in different locations, or specific cultivars may be referred to by different names in different regions (Al-Khalifah et al. 2012). Nevertheless, genetic diversity pertains to the genetic variation among date palm cultivars throughout their distribution area. Therefore, a scientific technique has been applied to identify true-to-type cultivars, such as genotype description based on morphological properties or the use of various molecular markers like RAPD, AFLP, ISSR, and microsatellite markers. It is recommended to combine ethnobotany and genetics to assess the biodiversity of date palm cultivars (Gros-Balthazard et al. 2020).

## 1.3 Date Production

Date palm trees begin to produce fruit between 4 and 5 years after being planted, and reach their maximum production between 10 and 15 years. They are capable of producing 40–80 kg, or even more, of dates per tree, and can live for up to 150 years. The majority of the worldwide date production comes from the Middle East. Saudi Arabia has the largest number of palm trees in the world, exceeding 25 million palm trees across more than 170,000 ha. In 2019, the country produced over 1.5 million metric tons of dates. According to research by Al-Abbad et al. (2011), there are over 84 million date palm trees in the Arab world, with Saudi Arabia having more than one-third of that total (General Authority for Statistics 2015). This can be attributed to various factors including religious, cultural, and environmental considerations. Researchers in Saudi Arabia have conducted studies to evaluate the qualities of fruits and seeds in order to maintain quality standards and preserve the identity of date varieties. This could ultimately lead to increased exports of palm crops (Al-Abdoulhadi et al. 2011).

### 1.4 Taxonomic and Ecological Characteristics

Date palms are monocotyledonous and go through several ripening phases including hababauk, kimri, khalal, rutab, and tamer. According to taxonomy, they are a subspecies of the Palmaceae family and the genus Phoenix (Krueger 2021). These fruit trees are dioecious, perennial, and evergreen. Date palms reproduce through sexual reproduction and vegetative propagation, and possess distinct morphological, anatomical, and environmental adaptations. The fruit requires the heat of summer to ripen and is typically grown in oases that have access to subterranean sources or springs for water. Fungal infections and fruit cracking are more of a risk during periods of rain or excessive humidity (Burt 2005). Favorable climatic conditions include long, hot summers with high temperatures throughout daytime and nighttime, and warm, sunny, dry winters with minimal frost (Jain 2011).

Various regions have their own unique date palm varieties, some of which have been renamed or moved to different areas. Additionally, there may be overlap in the naming of different cultivars. Phenotypic characteristics such as vegetative and flowering patterns, as well as the shape and size of the palm head and fronds, can help diagnose and identify these cultivars at various taxonomic levels.

## 2 Date Palm Importance and Utilization

### 2.1 Social Value

The culture of cultivating date palms has played a significant role in shaping our social and religious beliefs, as well as our heritage, eating habits, and social customs. Throughout history, the date palm tree has contributed to the lives of Arabs. It has been a staple food, building material for houses and landscaping (Ibrahim 2010). Additionally, it has been included in art, painting, and literary and artistic legacies. Date palms are cultivated wherever water is available. The role of the date palm has increased as farmers have recognized that it is a halophytic plant capable of tolerating higher levels of salinity than any other fruit tree Moreover, its production can remain stable in harsh environments where other fruit trees may fail. The palm tree can also reduce the atmospheric temperature and the level of pollutants resulting from modern industrial activities. In oases, the socioeconomic relevance of dates is particularly well recognized, where date trees thrive, and their fruits were once the main means of trade among people (Almadini et al. 2021). Dates are marketed as a popular fruit and confectionery item throughout the nation, with usage peaking during the Muslim fasting of Ramadan. Dates are also considered a great source of simple sugars and minerals for both humans and animals during times of scarcity. Low-grade parts of the harvest can also be used as a feed supplement for humans (Fatima et al. 2016).

## 2.2 Economic Values

The date production industry is a global agriculture industry that produced around 7 million metric tonnes (Mt) of fruit in 2012. The market value of this industry was over one billion USD. The date palm is an ancient crop with a history that demonstrates its significance. Recently, date palm plantations have been established in the southern hemisphere, Israel, and the United States (Johnson et al. 2015).

The date fruit grows primarily in high temperature regions in South West Asia and North Africa. The five most producing nations, which are Egypt, Saudi Arabia, Iran, Algeria, and Iraq, account for 75% of the overall production (Table 1). These countries also make up about 69% of the total production. When the following five important countries, including Pakistan, Sudan, Oman, United Arab Emirates, and Tunisia, are added, the percentage goes up to 90%. This indicates that the majority of the worldwide date production is concentrated in a number of countries in the same region (NCPD 2023).

## 2.3 Marketing

According to Technavio (2022), the date palm industry is estimated to grow to 8.64 billion USD. Arab Gulf citizens consume the most dates, but there is a large variation in consumption per capita, ranging from 68 to 164 g/day, as reported by multiple sources such as Aleid et al. (2015), Al-Mssallem (2018), Al-Mssallem et al. (2019a), Ismail et al. (2006), and Qazaq and Al Adeeb (2010). The country with the highest average daily consumption of date palm fruits is Saudi Arabia with 152 g/day at Rutab and Tamer stages, followed by Oman with an average of 109 g/day, as reported by Al-Mssallem et al. (2022). Consumption of date palm fruits per capita is relatively low in other countries, but date pits and immature dates that fall from palm trees are used as livestock feed. A certain amount of dates are wasted during production.

Significant quantities of dates are also wasted, with Kuwait having the highest rate of 13% and Saudi Arabia having the lowest rate of production waste at 1%, according to Frija et al. (2017). Date marketing varies by country, with the exception of the UAE and Saudi Arabia, where local production accounts for a small portion of export marketing. There are two general forms of date marketing: direct traditional marketing to consumers and marketing to existing local date palm plantations. In general, marketing channels for dates differ little from one another in the Middle East, including on-farm selling, local markets, merchants, date plantations, and consumer markets. The National Centre for Palms and Dates (NCPD) was established in Saudi Arabia in 2011 to focus on product quality and production efficiency, effective local and international marketing programs, and development of the date palms and date fruits sector. As each country has different legislation, there is no universally applicable set of marketing channels for dates (NCPD 2023).

**Table 1** Date palm production (ton) worldwide in 2019*

| Country | Production of dates (ton) | Rank |
|---|---|---|
| Egypt | 1,603,762 | 1 |
| Saudi Arabia | 1,539,756 | 2 |
| Iran | 1,307,908 | 3 |
| Algeria | 1,136,025 | 4 |
| Iraq | 639,315 | 5 |
| Pakistan | 483,071 | 6 |
| Sudan | 438,700 | 7 |
| Oman | 372,572 | 8 |
| United Arab Emirates | 323,478 | 9 |
| Tunisia | 288,700 | 10 |
| Libya | 174,850 | 11 |
| Kuwait | 105,867 | 12 |
| Morocco | 101,537 | 13 |
| Yemen | 64,375 | 14 |
| United State of America | 55,700 | 15 |
| Israel | 43,412 | 16 |
| Turkey | 41,570 | 17 |
| Qatar | 25,843 | 18 |
| Jordan | 23,375 | 19 |
| Mauritania | 21,926 | 20 |
| Chad | 21,458 | 21 |
| Niger | 19,769 | 22 |
| Somalia | 14,166 | 23 |
| Albania | 14,035 | 24 |
| Bahrain | 13,000 | 25 |
| Mexico | 12,365 | 26 |
| Palestine | 7729 | 27 |
| Syria | 3567 | 28 |
| Benin | 1454 | 29 |
| Kenya | 1100 | 30 |
| Mali | 670 | 31 |
| Cameroon | 638 | 32 |
| Peru | 367 | 33 |
| Namibia | 354 | 34 |
| Eswatini | 311 | 35 |
| Djibouti | 118 | 36 |
| Colombia | 16 | 37 |

*Source* NCPD (2023)

## 2.4 Research Advances

Although date palms are one of the most productive crops in arid, semiarid, tropical, and subtropical environments, it has undergone relatively limited research into its molecular genetics and genetics compared to other commercial fruit plants. However, there have been significant advances in genomic techniques in recent years. The genomes of the date palm and its organellar genomes have been sequenced by Al-Dous et al. (2011), Fang et al. (2012), Khan et al. (2012), Al-Mssallem et al. (2013), and Asaf et al. (2021). Many genotypes have been re-sequenced to identify single nucleotide polymorphisms (SNPs) (Thareja et al. 2018) or investigate domestication and marker-trait associations (Hazzouri et al. 2015, 2019; Gros-Balthazard et al. 2017).

Several marker resources, including RAPD, simple sequence repeats, inter-simple sequence repeats, amplified fragment length polymorphisms (AFLP), and others, have previously been utilized alongside SNPs for diversity studies as well as cultivar identification. Early sexual maturity is a crucial trait of the date palm. Since the date palm is dioecious, attempts have been applied to create specific markers for identifying early female plants. Additionally, molecular markers have been developed for the tree's resistance to brittle leaf disease (BLD) (Al-Khalifah et al. 2012; Gros-Balthazard et al. 2020).

The yield of date palms in the Arabian Peninsula has been severely affected recently by the red palm weevil (*Rhynchophorus ferrugineus* Olivier) (Al-Qahtani 2021). Advanced genomics technologies are being utilized at the International Center for Biosaline Agriculture (ICBA), located in the UAE, to address this biotic stress (ICBA 2018). This study aims to review the progress made in date palm genomics applications and identify future prospects for the field, despite the fact that there has been little progress in this area, given the significance of this crop for the livelihood of numerous farmers in the Arabian Peninsula.

Farmers traditionally propagate date palms using offshoots. However, since the early 1980s, the Center of Date Palm Research for Excellence at King Faisal University has been using in vitro plant micropropagation for rapid and effective date palm propagation that allows for genetic and physiological improvements. This method has been successful, according to Al-Ghamdi (1996) and several papers published by the College of Agriculture and Food Sciences at King Faisal University, including those by Al-Khayri and Al-Bahrany (2001, 2004a, b, 2012) and Al-Khayri (2001, 2002, 2003, 2011a, b, 2012). Research regarding tissue culture propagation has also been conducted in collaboration with various Saudi research institutions, such as King Faisal University, King Abdulaziz City for Science and Technology, the Ministry of Environment, Water and Agriculture, and King Saud University (Aleid et al. 2015). Interestingly, the in vitro tissue culture technique has proven effective in producing secondary metabolites of date palm on a large scale, as demonstrated in papers by Al-Khayri and Naik (2020, 2022) and Naik and Al-Khayri (2018, 2020).

### 2.5 Industrial Applications

Date palm trees are primarily grown for their fruit, which are typically consumed at two different stages of ripeness: Rutab and Tamer. However, unripe date palm fruits such as Kimri and Khalal are often used to create value-added products such as to pickles and chutney (Ashraf and Hamidi-Esfahani 2011; Ghnimi et al. 2017). There is a growing effort to incorporate dates and date-derived products into the daily human diet in an economical and efficient manner (El Hadrami and Al-Khayri 2012). In fact, several value-added products made from date fruits have been commercially introduced, like date biscuits, date cake, date bars, date paste, date jam, date jelly, granulated date sugar, date candy, date ice cream, date pudding, date butter, date syrup, carbonated and also non-carbonated beverages (Al-Hooti et al. 1997; Besbes et al. 2009; Phillips et al. 2009; Kulkarni et al. 2010; Ashraf and Hamidi-Esfahani 2011; Tang et al. 2013). Most of these products have been tested and found to exhibit high antioxidant activity (Tang et al. 2013).

The various woody parts of date palms, including leaflets, fronds, rough fibers, and trunks, can be used for handicrafts and architecture. For example, the leaflets and fronds can be transformed into mats, baskets, roofs, ropes, hand fans, huts, fences, and cordage. Trunks can also be used in construction, such as for building houses and bridges, as well as being used as fuel (Tengberg 2012; Anwar 2006). Rachises can be used to make paper, while young leaves and terminal buds can be eaten as vegetables (El Hadrami and Al Khayri 2012; Khiari et al. 2011). Furthermore, date production and cultivation create a significant number of careers in orchards during harvesting and processing of fruits (Jain 2012). Additionally, new products of date palm such as nutraceuticals have also been introduced to fully maximize the health benefits of dates, creating a chance for date valorization (El Hadrami and Al-Khayri 2012; Niazi et al 2017; Ghnimi et al. 2017; Sirisena et al. 2015; Chaira et al. 2009). Additionally, there is a growing trend towards using date palm by-products and waste to help produce industrial components, such as antibiotics, biopolymers, organic acids, and biofuels (Chandrasekaran and Bahkali 2013).

## 3 Date Palm Significance in Food Security

### 3.1 Climate Change Implications

The prevailing climate in Saudi Arabia is arid, which is susceptible to the adverse effects of climate change. Climate change has both direct and indirect consequences on food and nutrition security. The effects of climate change on food security can be seen through food accessibility, food availability, food supply stability and price volatility. Temperature and rainfall are two elements that can be used to assess future trends of climate change (Tarawneh and Chowdhury 2018).

Climate change can directly affect the date palm economy by impacting the production of dates. It has been reported that countries in the Middle East have experienced a decrease in their annual income from date palms due to plant diseases and water shortages caused by climate change, which in turn has affected food security. In Saudi Arabia, certain areas that are currently suitable for growing date palms will no longer be suitable in the future, and vice versa (Shabani et al. 2012). By 2100, there will be a significant reduction in the climate suitability for date palm production in Saudi Arabia (Allbed et al. 2017).

### *3.2 Relevance to Food Security Strategies*

It is evident that the local food production in Saudi Arabia is inadequate to meet domestic demands. Various strategies have been proposed to establish opportunities for creating a sustainable agricultural sector and promoting national crops such as date palms (MEWA 2018). There are several entities that contribute significantly in food and nutrition security, including the National Centre for Palms and Dates (MEWA 2023). The NCPD has played a significant role in the development of the date sector in Saudi Arabia, primarily by improving the efficiency and quality of dates. The main focus of the NCPD is to amplify the quality of dates, increase local consumption of dates, and raise the value of Saudi Arabia's date exports (NCPD 2023). The local sufficiency of date production in Saudi Arabia was achieved and reached 125% in 2022 (MEWA 2023). It is well-documented that date palm cultivation can help achieve food security (Fiaz et al. 2018).

### *3.3 Poverty Alleviation and Farmer Livelihood Protection*

Saudi Arabia is ranked as the world's second largest producer and exporter of dates (according to Table 1), producing approximately 1.5 million tons each year. The cultivation and consumption of date palm can significantly contribute to ensuring food and nutritional security not only in Saudi Arabia but also in other regions of the world. This is due to its high nutritional value, affordability as a source of energy and nutrients (Al-Farsi and Lee 2008; Al-Mssallem et al. 2019b; Al-Mssallem 2020), ability to tolerate harsh climatic conditions (Almutawa 2022), and economic potential (Bisht and Singh 2020). It is considered an important crop for combating food insecurity and malnutrition, and with the growing global demand for dates, Saudi Arabia is well-positioned to meet this demand. The cultivation of date palm is an economic and sustainable crop that requires minimal resources, making it a national crop that is perfectly suited to Saudi Arabia's climatic conditions (Fernández-López et al. 2022). Saudi Arabia has been actively promoting the cultivation of date palm in other nations, particularly in Africa and Asia, where the crop is well-suited to many arid and semi-arid regions (Bisht and Singh 2020). The cultivation of date palms can help provide food security in these regions by reducing dependence on imported food and increasing local food production (Al-Shahib and Marshall 2003; Bisht and Singh 2020).

Cultivating date palms can contribute to food security in these regions. It can reduce dependence on imported food and increase local food production, as noted by Al-Shahib and Marshall (2003) and Bisht and Singh (2020). Furthermore, selling dates can provide a source of income for small-scale farmers, thereby improving their livelihoods. In addition, the economic growth of the country can benefit from exporting dates. Dates are consumed in various forms, including fresh, dried, and in the production of sweets (Al-Alawi et al. 2017). Date palms are not only used as a food source but also as a versatile crop. For example, their leaves can be used for roofing, fencing, and making baskets. The date palm tree trunk is utilized for construction, and the seeds are used to make animal feed. This creates further income and employment opportunities for many people, especially in rural areas (Al-Dous et al. 2011; Al-Alawi et al. 2017). This industry can create jobs for farmers, laborers, technicians, and other workers, helping to support local economies and provide a source of income for families (Bisht and Singh 2020). Moreover, a few years ago, Saudi Arabia established the Kingdom's Dates Aid Program. The program targets 72 countries across four continents (Asia, Africa, South America, and Europe) for 2023. The weight of the date gift for 2023 is over 19,000 tons, of which 4000 tons will be supplied through the strategic partner, The World Food Program, at a total cost of 136 million Saudi Riyals. This will benefit 14 million people annually. Since 2002, the program has delivered and distributed 4000 tons annually, with a total generous gift project of 84,000 tons delivered to 130 international stations (NCPD 2023).

Overall, the date palm played a significant role in alleviating poverty and protecting livelihoods in many regions, including Saudi Arabia. The cultivation and use of date palms provide employment opportunities, generate income, ensure food security, preserve cultural heritage, protect the environment, diversify income, and promote community development. Therefore, they are valuable assets that can support sustainable development and improve the lives of millions of people.

## 4 Date Palm Significance in Nutritional Security

### *4.1 Nutritional Value and Health Benefits*

It is common knowledge that carbohydrates (CHOs) are the main chemical component in date fruits. These account for 53% in Rutab and 73% in Tamer stage. The CHOs content includes simple sugars like fructose, glucose, and sucrose, as well as non-starch polysaccharides (NSPs). Date fruits also have small quantities of fat and protein, with an average of 0.14% and 1.5% in Rutab, and 0.28% and 1.93% in Tamer, respectively. Furthermore, date fruits are a great source of macro- and micro-minerals such as magnesium, potassium, and selenium. However, water- and fat-soluble vitamins are present in lower quantities, particularly at Rutab stage (see Table 2 and Fig. 1) (Septembre-Malaterre et al. 2018; Al-Farsi and Lee 2008). It is a fact that date palm fruits are frequently consumed at both Tamer and Rutab stages. Despite the high content of easily digested and absorbed simple sugars in date fruits (glucose and fructose), the glycaemic load and glycaemic index values of most date varieties fall into the low category (see Table 3) (Miller et al. 2003; Ba-Jaber et al. 2006; Ali et al. 2009; Alkaabi et al. 2011; Al-Mssallem and Brown 2013; Al-Mssallem 2014; AlGeffari et al. 2016; Gourchala et al. 2016).

**Table 2** Nutritional composition of date palm fruits at Rutab and Tamer stages

| Nutrients | Rutab stage | Tamer stage |
|---|---|---|
| Moisture (g/100 g) | 44.70 | 23.9 |
| Macronutrients (g/100 g) | | |
| Glucose | 22.8 | 30.4 |
| Fructose | 19.4 | 27.6 |
| Sucrose | 4.0 | 4.7 |
| Total simple sugars | 46.2 | 62.7 |
| Insoluble NSPs | 5.9 | 6.7 |
| Soluble NSPs | 1.00 | 3.6 |
| Total NSPs | 6.9 | 10.3 |
| Total carbohydrates | 53.1 | 73.0 |
| Protein | 1.5 | 1.9 |
| Fat | 0.1 | 0.3 |
| Micronutrients | | |
| Minerals (mg/100 g) | | |
| Sodium (Na) | 90.9 | 32.9 |
| Potassium (K) | 486 | 713 |
| Magnesium (Mg) | 43.3 | 64.2 |
| Calcium (Ca) | 20.2 | 70.7 |
| Phosphor (P) | 41.0 | 58.1 |
| Manganese (Mn) | 0.3 | 0.3 |
| Iron (Fe) | 0.6 | 0.8 |
| Zink (Zn) | 0.2 | 0.3 |
| Copper (Cu) | 0.2 | 0.2 |
| Selenium (Se) | 0.2 | 0.3 |
| Vitamins (mg/100 g) | | |
| Water soluble vitamins | N/A | 5.8 |
| Fat soluble vitamins | N/A | 0.02 |

*Sources* Tang et al. (2013), Al-Shahib and Marshall (2003), Al-Farsi and Lee (2008)

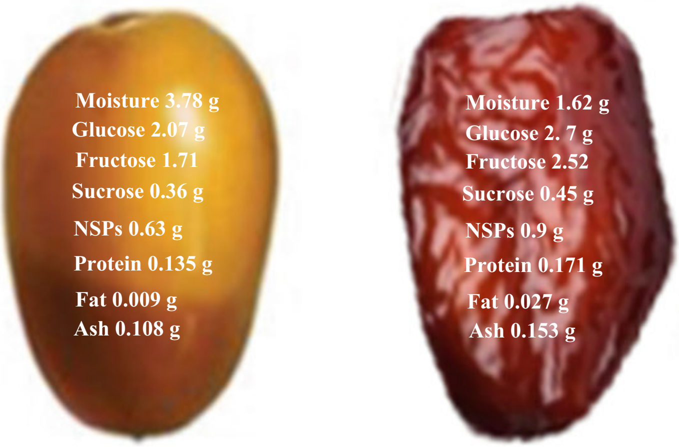


**Fig. 1** The chemical composition of Rutab and Tamer in gram per one date fruit (9 g). Figure was constructed based on data presented by Septembre-Malaterre et al. (2018), Al-Farsi and Lee (2008)

Date fruits are a rich source of NSPs, with a content of 10/100 g, which accounts for approximately 13% of total carbohydrates. Recently, it has been found that consuming 7–9 date fruits per day can provide approximately one-fifth of the recommended dietary allowance (RDA) of NSPs and magnesium, and one-fourth of potassium (Al-Mssallem et al. 2019a). Due to its high contents of NSPs, date palm fruit is considered a natural laxative for promoting regular bowel movements and regulating intestinal transit (Al-Farsi and Lee 2008; Manickavasagan et al. 2012; Otles and Ozgoz 2014). In addition, the NSPs present in date fruits can contribute to reducing the development risk of overweight and obesity through increasing satiety, decreasing appetite, controlling energy intake (Gourchala et al. 2016; Kumar et al. 2012; Kristensen and Jensen 2011). It has been noted that there is a negligible relation between date fruit consumption and weight gain (Al-Mssallem et al. 2019a).

Date fruits possess high antioxidant activity, ranging from 580 to 1656 μmol Trolox equivalents antioxidant activity/100 g FW (Al-Farsi et al. 2005; Saafi et al. 2009; Al-Turki et al. 2010), because of the existence of bioactive constituents such as polyphenols, carotenoids, phenolic acids, and flavonoids (Al-Farsi and Lee 2008, Al-Farsi et al. 2005; Vayalil 2014; Bouhlali et al. 2017; Septembre-Malaterre et al. 2018; Hamad et al. 2015; Vayalil 2014). Date fruits have been demonstrated to act effectively as scavengers of free radicals, where these bioactive substances can absorb and neutralize any intermediates of free radicals that result from oxidation reactions in the human body (Al-Turki et al. 2010; Guaadaoui et al. 2014; Porrini and Riso 2008). There is a significant relation between the antioxidant activity in date fruits and their total content of phenolic compounds (Mansouri et al. 2005; Awad et al. 2011). Moreover, constituents of date fruits, such as insoluble and soluble NSPs, may contribute to delaying the progression of diabetes-related complications (Malviya et al. 2010; Sluijs et al. 2010; Schulze et al. 2004; Stevens et al. 2002; Meyer

**Table 3** Available carbohydrates (CHOs), glycaemic index (GI) and glycaemic load (GL) values, and glycaemic index and glycaemic load categories of date palm fruits at Tamer stage*

| Dates varieties | Total CHO | Available CHO | Available CHO in serving size | GI value | GI category | GL value | GL category |
|---|---|---|---|---|---|---|---|
| Ajwah, Saudi Arabia | 71.3 | 61.3 | 16.4 | 56 | Medium | 9 | Low |
| Birhi, Saudi Arabia | 72.8 | 57.3 | 15.4 | 64 | Medium | 10 | Low |
| Birhi, UAE | 72.8 | 57.3 | 15.4 | 49 | Low | 8 | Low |
| Birhi (mean of 2 studies) | 72.8 | 57.3 | 15.4 | 56 | Medium | 9 | Low |
| Bo ma'an, UAE | 76.4 | 59.0 | 15.9 | 31 | Low | 5 | Low |
| Bo ma'an, UAE | 71.6 | 69.0 | 18.6 | 46 | Low | 9 | Low |
| Bo ma'an (mean of 2 studies) | 74.0 | 64.0 | 17.2 | 38 | Low | 7 | Low |
| Dabbas, UAE | 70.8 | 68.4 | 18.4 | 49 | Low | 9 | Low |
| Deglet Noor, Algeria | 84.1 | 70.9 | 19.1 | 52 | Low | 10 | Low |
| Fardh, Oman | 63.7 | 52.9 | 14.2 | 52 | Low | 7 | Low |
| Fardh, UAE | 72.5 | 69.9 | 18.8 | 54 | Low | 10 | Low |
| Fardh (mean of 2 studies) | 68.1 | 61.4 | 16.5 | 53 | Low | 9 | Low |
| H'mira, Algeria | 72.2 | 58.4 | 15.7 | 48 | Low | 8 | Low |
| Khalas (mean of 6 studies) | 70.2 | 64.2 | 17.3 | 48 | Low | 8 | Low |
| Khasab, Oman | 67.2 | 54.8 | 14.8 | 55 | Low | 8 | Low |
| Khudhary, Saudi Arabia | 74.5 | 61.3 | 16.5 | 58 | Medium | 10 | Low |
| Khudhary, Saudi Arabia | 74.5 | 61.3 | 16.5 | 61 | Medium | 10 | Low |
| Khudhary (mean of 2 studies) | 74.5 | 61.3 | 16.5 | 59 | Medium | 10 | Low |
| Lulu, UAE | 70.8 | 69.0 | 18.6 | 53 | Low | 10 | Low |
| Maktoomi, Saudi Arabia | 72.9 | 61.3 | 16.5 | 71 | High | 12 | Medium |
| Medjool, Saudi Arabia | 70.9 | 61.3 | 16.5 | 55 | Low | 9 | Low |
| Nabtat-ali, Saudi Arabia | 72.2 | 61.3 | 16.5 | 60 | Medium | 10 | Low |
| Nabtat-seif, Saudi Arabia | 74.6 | 61.3 | 16.5 | 54 | Low | 9 | Low |

(continued)

**Table 3** (continued)

| Dates varieties | Total CHO | Available CHO | Available CHO in serving size | GI value | GI category | GL value | GL category |
|---|---|---|---|---|---|---|---|
| Nabut Seif, Riyadh, Saudi | 69.9 | 61.3 | 16.5 | 64 | Medium | 11 | Medium |
| Nabut Sultan, Saudi Arabia | 69.9 | 61.3 | 16.5 | 51 | Low | 8 | Low |
| Osilah, Saudi Arabia | 60.6 | 53.5 | 14.4 | 56 | Medium | 8 | Low |
| Rabiea, Riyadh, Saudi | 69.9 | 61.3 | 16.5 | 55 | Low | 9 | Low |
| Rashodia, Saudi Arabia | 74.3 | 61.3 | 16.5 | 51 | Low | 8 | Low |
| Ruthana, Saudi Arabia | 69.9 | 61.3 | 16.5 | 54 | Low | 9 | Low |
| Ruthana, Qassim, Saudi | 68.1 | 61.3 | 16.5 | 52 | Low | 9 | Low |
| Ruthana (mean of 2 studies) | 69.0 | 61.3 | 16.5 | 53 | Low | 9 | Low |
| Sabaka, Saudi Arabia | 71.9 | 61.3 | 16.5 | 55 | Low | 9 | Low |
| Saqai, Saudi Arabia | 68.8 | 61.3 | 16.5 | 44 | Low | 7 | Low |
| Saqai, Saudi Arabia | 69.9 | 61.3 | 16.5 | 59 | Medium | 10 | Low |
| Saqai (mean of 2 studies) | 69.3 | 61.3 | 16.5 | 51 | Low | 8 | Low |
| Sellaj, Saudi Arabia | 72.5 | 61.3 | 16.5 | 74 | High | 12 | Medium |
| Sellaj, Saudi Arabia | 69.9 | 61.3 | 16.5 | 56 | Medium | 9 | Low |
| Sellaj (mean of 2 studies) | 71.2 | 61.3 | 16.5 | 65 | Medium | 11 | Medium |
| Shaqra, Saudi Arabia | 74.7 | 61.3 | 16.5 | 43 | Low | 7 | Low |
| Shishi, Saudi Arabia | 69.6 | 61.3 | 16.5 | 50 | Low | 8 | Low |
| Sukkary, Saudi Arabia | 69.9 | 61.3 | 16.5 | 47 | Low | 8 | Low |
| Sukkary, Saudi Arabia | 64.4 | 61.3 | 16.5 | 43 | Low | 7 | Low |
| Sukkary (mean of 2 studies) | 67.1 | 61.3 | 16.5 | 45 | Low | 7 | Low |

(continued)

**Table 3** (continued)

| Dates varieties | Total CHO | Available CHO | Available CHO in serving size | GI value | GI category | GL value | GL category |
|---|---|---|---|---|---|---|---|
| Tinnisine, Algeria | 68.6 | 56.1 | 15.1 | 44 | Low | 7 | Low |
| Um-Kabar, Saudi Arabia | 72.3 | 61.3 | 16.5 | 58 | Medium | 10 | Low |
| Wannanah, Saudi Arabia | 74.0 | 61.3 | 16.5 | 51 | Low | 8 | Low |

**Source* Al-Mssallem (2020)

et al. 2000; Salmeron et al. 1997). However, the role of date fruits' components in managing diabetes needs to be fully elucidated.

The components of date fruits have an oxytocin-like effect which reduces the requirement of labour induction and augmentation by prompting uterine myometrial cells, and increasing the sensitivity of the uterus (Al-Kuran et al. 2011; Kordi et al. 2014; Razali et al. 2017). Additionally, consuming date fruits has a beneficial impact on reducing postpartum haemorrhage after delivery and increasing breastfeeding milk production (Khadem et al. 2007). Date fruits are considered an excellent option for breakfast on a daily basis, particularly during Ramadan (Al-Shahib and Marshall 2003). They are great source of instant energy due to their natural readily absorbed glucose content (Gourchala et al. 2016; Ali et al. 2009; Khan et al. 2008; Al-Farsi and Lee 2008; Al-Shahib and Marshall 2002; Ahmed and Ahmed 1995). From an Islamic perspective and based on the recommendation of Prophet Mohammed (peace be upon him), it is strongly advised to break the fast by consuming seven date fruits a day at breakfast (Narrated by Muslim).

## *4.2 Physico-chemical Properties*

Date fruits go through five stages of ripening, which are commonly called by their Arabic names: Kimri, Khalal, Bisir, Rutab, and Tamer (Fig. 2). The most commonly consumed stages of ripening are Rutab and Tamer (Fig. 1). The moisture content during the Kimri stage is approximately 85%, which decreases as it matures to approximately 18% during the Tamer stage. At the Kimri stage, the fruit color is typically green and starts to turn to red, orange, or yellow, depending on the variety during the Bisir stage. The size, shape, and weight of date palm fruits vary based on their varieties and growth conditions (Fig. 2). For example, the average weight of dates can range from 2 to 60 g (Al-Farsi and Lee 2008).

Date fruits are regarded to be an excellent source of simple sugars, specifically glucose (on average 30%), fructose (28%), and sucrose (4%). They contain a low concentration of proteins (1.5–1.93 g/100 g FW) and fats (0.14–0.28 g/100 g FW),

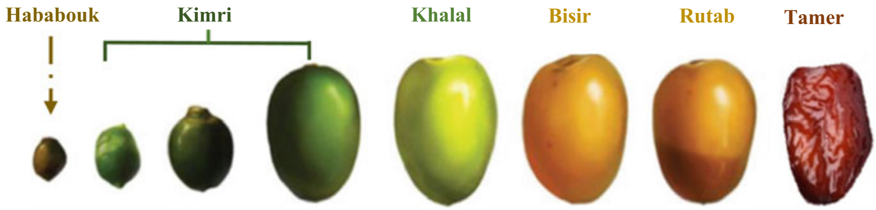


**Fig. 2** The variation in the size, weight, and shape of date palm fruit during development stages. *Sources* Al-Mssallem et al. (2013), Al-Mssallem (2020)

according to various studies (Ahmed and Ahmed 1995; Al-Hooti et al. 1997; Miller et al. 2003; Al-Farsi et al. 2005; AlKaabi et al. 2011; Gourchala et al. 2016).

Micronutrients found in dates include minerals and vitamins. Date fruits contain a significant amount of macro-minerals such as magnesium, potassium, phosphorus, sodium, and calcium, as reported by Khan et al. (2008), Al-Farsi and Lee (2008), AlJuhaimi et al. (2014), Hossain (2015), and Gourchala et al. (2016). Additionally, micro-minerals like iron, manganese, zinc, copper, and selenium have been found in date fruits in small to moderate amounts. The most abundant mineral in date fruits is potassium, followed by magnesium, according to Khan et al. (2008), Al-Farsi and Lee (2008), and AlJuhaimi et al. (2014). Date fruits also contain fat- and water-soluble vitamins in low to moderate quantities. Small amounts of fat-soluble vitamins A and E, in the form of β-carotene and α-tocopherol, respectively, have been detected. Furthermore, date fruits have been found to contain ascorbic acid (vitamin C) and B complex vitamins such as thiamine, riboflavin, niacin, pyridoxal, and folic acid, as noted by Guo et al. (2003) and Al-Farsi and Lee (2008). Date fruits contain moderate concentrations of vitamin C, with a concentration of about 3.9 mg/100 g FW (Al-Farsi and Lee 2008).

## 5 Conclusion and Prospects

The date palms and their fruits are important contributors to food and nutritional security due to their high nutritional content, functional properties, and potential industrial applications. It is a fact that the essential chemical substances of date palm fruits are glucose and fructose, providing instant energy and recommended for breaking the fast and treating hypoglycemia. Date palm fruits are also a good source of dietary fiber, improving gastrointestinal functions, controlling weight, delaying gastric emptying, and lowering the glycemic impact of carbohydrates. Additionally, they are rich in potassium, regulating blood pressure and heart rate. By enhancing harvesting, storage, and distribution practices and adopting the right global marketing approaches, date palm fruits can be a premium quality fruit and related value-added commodity. The functional and nutritional benefits suggest that date palm fruit components can be potential ingredients for therapeutic and nutraceutical applications, requiring further research to exploit them as healthy food. Further research is necessary to assess the functional qualities of date palm fruit constituents as functional food ingredients. This data can help government and agricultural organizations with strategic planning by identifying new locations or marginal areas for date palm cultivation. It is recommended to develop a useful database for relevant research and operational sectors while monitoring food security in Saudi Arabia at individual and public levels.

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# Chapter 16
# Genetically Modified Food: Potentiality for Food and Nutritional Security in Saudi Arabia

**Muneera Q. Al-Mssallem, Jameel M. Al-Khayri, Bashayer H. Almagthali, Hayam S. Abdelkader, Khadija I. Alnabbat, and Muhammad N. Sattar**

**Abstract** The growing global population has created a demand for new forms of sustenance, such as genetically modified (GM) food, which have been a topic of debate for many years. Some people believe that GM foods are safe and can be a valuable tool for improving food production and nutrition. Others are concerned about the potential risks of GM foods, such as the possibility that they could harm human health or the environment. Biotechnology has made it possible to genetically modify agricultural crops to increase production, improve quality, resist disease and biotic and abiotic stress factors, while considering sustainability and environmental preservation. This can play a significant role in food and nutritional security. Genetic modification offers an alternative approach to traditional breeding methods to introduce desired traits into plants that may not be readily available in the crop's gene pool. However, GM foods raise concerns relating to social, economic, health, and ethical

M. Q. Al-Mssallem (✉) · K. I. Alnabbat
Department of Food and Nutritional Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: mmssallem@kfu.edu.sa

K. I. Alnabbat
e-mail: kalnabbat@kfu.edu.sa

J. M. Al-Khayri · B. H. Almagthali
Department of Agricultural Biotechnology, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: jkhayri@kfu.edu.sa

B. H. Almagthali
e-mail: balmaqthali@kfu.edu.sa

H. S. Abdelkader
Department of Virus Research, Molecular Biology Lab, Plant Pathology Research Institute, Agriculture Research Center (ARC), Cairo 12619, Egypt
e-mail: hsaabdelkader@arc.sci.eg; hsabdelkader@uj.edu.sa

M. N. Sattar
Central Laboratories, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: mnsattar@kfu.edu.sa



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issues. GM foods use genetic modification technology, including gene editing, and plant tissue culture, to improve their characteristics. The potential benefits of GM foods include improved human health and reduced environmental impact due to higher yields and pest resistance, but there are concerns about manipulating the natural order and potential unintended consequences. There is still a lot of uncertainty about the safety and benefits of GM foods. This uncertainty has led to a lack of trust among consumers, which has hindered the adoption of GM foods in many countries. Social trust is a key factor that influences consumer attitudes towards GM foods. Governments around the world regulate GM crop plants or their by-products differently. The US and Canada are more lenient, while the European Union requires mandatory labelling for any food product containing even a small amount of GM material. Public perception of GM food in Saudi Arabia is relatively low due to a lack of understanding, transparent regulations, and insufficient communication from authorities. Biosafety assessments aim to ensure that new food products produced using biotechnology are safe for human consumption and the environment. Saudi Arabia has regulations governing GM organisms and products, and it has advanced various fields such as crop breeding and development, biodegradable plastics, and utilizing biotechnology to fight malnutrition, drought, and salinity. Monitoring GM food is essential to comply with safety guidelines and regulations. It is important to understand and address public concerns in order to responsibly adopt and effectively communicate about GM foods in the context of food production and sustainability. This chapter highlights the potential contribution of GM foods to food and nutritional security and emphasizes their benefits and hazards to humans and the environment.

**Keywords** Abiotic stress · Consumer perception · Ecological consequences · Environmental safety · Genome editing · Industrial applications · Public perception · Social trust

## 1 Introduction

Food is essential for human survival as it provides the necessary daily nutrients to maintain overall health (McAuliffe et al. 2020). Due to the increasing global population and decreasing availability of arable land, it is necessary to develop crops that have high yield potential, enhanced nutritional value, and are resilient to environmental stressors (Roberts and Mattoo 2018). Genetically modified (GM) foods have the ability to enhance resistance to pests, diseases, abiotic stress, nutritional value, and postharvest traits (Tabashnik et al. 2009). Genetic modification and engineering have paved the way for the production of GM crops that possess superior characteristics and innovative food products (Yali 2022). Genetic engineering, made possible by recent advances in genomics and tissue culture methods, is currently the most widely used technique for crop modification (Demirer et al. 2021).

The use of genetic modification in the production of GM foods raises concerns regarding potential risks to human health, both short-term and long-term. In fact, GM foods have generated a global debate in terms of their potential hazards and limited understanding of their benefits (Kuiper et al. 2001). Consumer attitudes towards GM foods are influenced by risk perceptions, naturalness, knowledge, and social trust (Farid et al. 2020; Magnusson and Hursti 2002). Trust is crucial in shaping public perception and adoption of GM foods, particularly among those with limited knowledge of the technology (Vindigni et al. 2022). Concerns about the short- and long-term impact of GM foods on human health have contributed to consumer skepticism (Frewer 2003; Öz et al. 2018).

The regulatory agency in Saudi Arabia, such as the Saudi Food and Drugs Authority (SFDA), evaluates and regulates GM food and crops in the Kingdom. The purpose of this requirement is to ensure that the chemicals used in the production process adhere to mandated safety standards. Additionally, the SFDA may also seek assurances about the product's composition, including the absence of GM organisms and post-harvest treatment. These measures are implemented to guarantee that food items meet necessary safety and quality criteria before they are allowed for sale within the Saudi markets (SFDA 2021). Similarly, regulatory agencies like the FDA, EPA, and USDA regulate and evaluate GM crops in the US (Entine et al. 2021; Zetterberg and Edvardsson Björnberg 2017). Meanwhile, the European Union is more cautious to GM foods and requires labelling for any food product that contains even a minimal amount of GM material (Wenner 2018). This labelling requirement is intended to give consumers the opportunity to choose whether or not to consume GM foods. However, the Islamic perspective on GM food is complex and goes beyond classifying it as halal (permissible) or haram (forbidden), although this remains an important aspect. Three primary objections to genetic modification include the belief that it interferes with divine creation, potential harm to human health, and the use of prohibited resources. Saudi Arabia, the Islamic Food and Nutrition Council of America, the Islamic Jurisprudence Council, the Majelis Ulama Indonesia, the Majlis Ugama Islam Singapura, the government of Malaysia, and the Muslim World League are highly respected organizations known for their knowledge and expertise in Halal food products. This includes products produced through biotechnology, in accordance with Islamic beliefs and practices. In fact, Islamic doctrine divides all possessions into permissible and prohibited categories. Non-edible food items are considered harmful to humans, causing their followers to view them as taboo. Islamic dietary laws prohibit the consumption of certain foods, such as blood, carrion, pork, animals that have died through beating, suffocation, or falling, and animals sacrificed to idols. Nevertheless, the consumption of meat from wild animals killed by trained hunting animals is allowed. Although genetic modification has the potential to benefit human health, it also brings uncertain risks (Erol 2021). The Islamic perspective on GM foods surpasses determining their permissibility or prohibition. As per the Islamic Jurisprudence Council, consuming food items obtained from GM organism plants is considered acceptable for individuals following the Islamic faith. However, some experts and scholars believe that food products derived from GM plants might be forbidden if they contain DNA from restricted foods, such as soy products with swine DNA. Modifying these food items using gene editing techniques can ensure their permissibility. The Quran instructs individuals to consume the provisions given to them and offer gratitude to Allah, assuming they worship this Almighty deity.

# 2 Genetically Modified Food

## *2.1 Definition of Genetically Modified Food*

GM foods are developed using genetic engineering techniques that involve changing the genetic material of an organism. This can be achieved by introducing particular genes from one organism to another, even if they are unrelated species, for the purpose of imparting desired characteristics. The genetic makeup of GM organisms is altered in a way that is not natural, and cannot happen through normal mating or recombination (WHO 2014). This definition covers a broad range of organisms, including plants, animals, and microorganisms that have undergone genetic engineering using various techniques. These techniques involve genetic engineering methods, typically involving the isolation and transfer of specific genes that encode desired traits into the target organism. The most commonly used methods for genetic engineering include recombinant DNA technology, gene transfer using biolistic particle bombardment (gene gun), and agrobacterium-mediated gene transfer (Abbott et al. 2008).

Traditional breeding plays a significant role in improving crop varieties (Khush 2001). However, this approach has limitations, including time-consuming processes and the inability to introduce certain traits (Wani et al. 2016). To overcome these limitations, new technologies, such as genetic engineering, have been introduced. These technologies allow for the direct transfer of specific genes and provide desired traits in new products (Alrawi and Al-rawi 2022; Babar et al. 2020; Domingo and Bordonaba 2011; James 2014). Gene-editing techniques, such as CRISPR, offer precision and speed enabling targeted modifications and faster development of improved crop varieties compared to traditional breeding methods (Lyzenga et al. 2021).

## *2.2 Public Concerns*

The issue of GM foods elicits conflicting opinions in public discourse. Genetic modification is not inherently beneficial, but it serves as a way of reconciling the interests of scientific sectors that serve the public and private domains (Evans 2002). The effects of GM foods can have both benefits and drawbacks, as they can indirectly impact organisms that consume or interact with crops, and also have broader effects on the food chain due to changes in populations of other organisms (Singh et al. 2006). The findings of an online survey carried out by Farid and colleagues (2020) showed that nearly half of all consumers read food labels, and a considerable proportion of the overall population thinks that GM products ought to be labelled and subjected to allergy tests (Farid et al. 2020). Consumer perspectives on GM foods are impacted by their self-assessment and basic understanding of the product. Consumers in the European Union have shown resistance towards purchasing GM foods owing to perceived risks and advantages, whereas Chinese consumers generally have a pessimistic outlook towards GM foods (Magnusson and Hursti 2002). Many consumers who choose not to buy GM foods may lack proper knowledge, whereas those who have learned about it tend to acquire their information from online sources and social media. Interestingly, people tend to have more favorable opinions toward gene technology applied in the medical field rather than in food production (Frewer et al. 2014). Concerns regarding GM foods stem mainly from the technical risk assessments that highlight potential issues and the perceived unpredictability of the outcomes (Bawa and Anilakumar 2013). Individuals who have a limited understanding of gene technology tend to perceive it as riskier and are less accepting of it. The attitudes of consumers toward GM foods vary worldwide and are influenced by numerous factors, such as their perceptions, level of knowledge, societal trust, health expectations, beliefs about the naturalness of food, and attitudes toward labelling (Siegrist and Hartmann 2020).

## *2.3 Traditional Crop Breeding and the Need for Genetically Modified Food*

Traditional breeding methods have proven effective in developing better crop varieties over time. One prominent example is the Green Revolution of the mid-twentieth century, which led to the creation of high-yielding strains of rice and wheat that boosted food production and aided in reducing hunger worldwide (Khush 2001). Traditional breeding has also been utilized to enhance crops' resistance to diseases, droughts, and nutritional deficiencies (Tester and Langridge 2010). However, traditional breeding does have its limitations- it is often time-consuming, requiring several years to produce new strains with desirable traits, and certain traits may be absent from the crop's gene pool, making it difficult to introduce them through breeding alone (Wani et al. 2016). As an alternative, genetic modification or engineering presents an option for crop improvement, allowing for the direct transfer of specific genes from one species to another, even if they are not inherently related. This technology permits the integration of desirable traits absent from a crop's gene pool. GM foods can address several challenges that traditional breeding methods face, including increased resistance to pests and diseases, greater tolerance to environmental pressures such as drought or salinity, improved nutritional content, and better post-harvest properties (Domingo and Bordonaba 2011; James 2014). One example is the creation of Bt crops, which contain a toxin from the Bacillus thuringiensis bacterium and have significantly reduced the use of chemical insecticides and improved pest control in crops such as cotton and maize (Tabashnik et al. 2009).

The current rate of global population growth may exceed the world's ability to sustain it through food production, and GM crops and foods have potential solutions to this problem. However, concerns about the impact of GM organisms on human socioeconomic conditions, environmental and health risks, may limit their widespread adoption and create public apprehension (Mofijur et al. 2021). On the other hand, GM crops and foods have positive effects on the socioeconomic characteristics of farmers in developing countries and have minimal negative impacts on the environment and human health, while providing numerous benefits (Li et al. 2014). The increasing global population and decreasing arable land necessitate the development of cultivars with high yield potential, enhanced nutritional value, and resilience to environmental stressors. Breeding methods like mutagenesis, intergeneric crosses, and translocation breeding have been used to enhance crop quality (Gupta et al. 2021). Genetic engineering has also facilitated the development of GM crops that are resistant to unfavorable environmental factors (Babar et al. 2020). Regulatory frameworks for GM crops use a process or product-focused approach to conduct a comprehensive risk analysis of their impact on the environment and public health (Gupta et al. 2021). Figure 1 provides an overview of major milestones in plant breeding, highlighting key advancements and breakthroughs throughout history. It showcases transformative shifts in plant breeding techniques, from ancient domestication and selective breeding to modern innovations such as transgenic breeding, mutational breeding, marker-assisted selection (MAS), and genome editing. These milestones have played a vital role in shaping the field, enabling scientists to enhance crop characteristics and develop improved plant varieties (Van Vu et al. 2022).

### *2.4 The New Era of Genome Modifications Through Genome Editing for Sustainable Crop Production*

Scientists have developed several molecular tools for the precise modification of plants. In 2005, zinc finger nucleases (ZFNs) were developed and used to improve plant traits in *Nicotiana tabacum* plants (Raza et al. 2021). ZFNs are synthetic endonucleases that are composed of a designed zinc finger protein (ZFP) joined to the cleavage domain of a restriction enzyme (FokI) (Paschon et al. 2019). ZFNs can be redesigned to cleave new targets by creating ZFPs with new selected sequences. The cleavage event instigated by the ZFN causes cellular repair processes that in turn mediate efficacious manipulation of the desired locus.

Five years later, transcription activator-like nucleases (TALENS) were developed as a new GE technique (Raza et al. 2021). In 2010, transcription activator-like nucleases (TALENs) were developed as a new genome editing technique. TALENs introduce specific DNA double-strand breaks (DSBs), as an alternative method to ZFNs for GE (Forner et al. 2022). TALENs and ZFNs contain a FokI nuclease, which is non-specifically fused with a modifiable DNA-binding domain. This DNA-binding domain possesses highly conserved repeats acquired from transcription activator-like

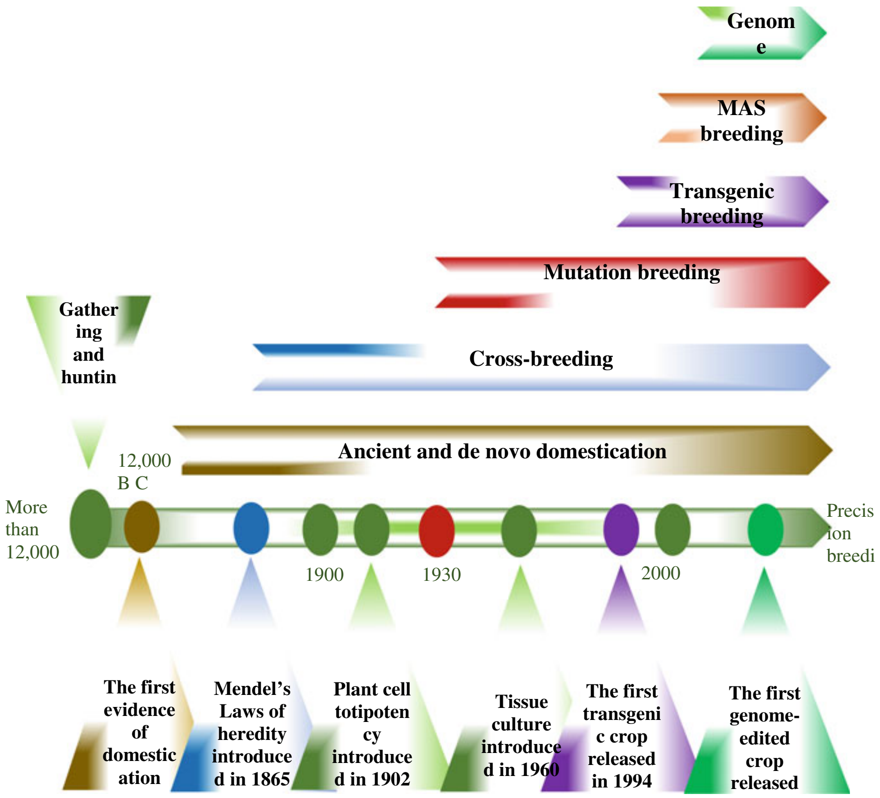


**Fig. 1** Significant milestones in the field of plant breeding. These milestones include the start of domestication and initial plant breeding around 12,000 B.C., the discovery of Mendel's laws of genetics, the invention of totipotency of plant cells in the early 1900s, the introduction of in vitro tissue culture in 1960, the development of transgenic breeding using Agrobacterium-mediated techniques, the introduction of mutational breeding using chemical or physical agents in the 1930s, the utilization of biochemical markers in marker-assisted selection (MAS) breeding, and the recent revolution of genome editing approaches in precision plant breeding. The release of the first genome-edited crop, high oleic acid soybean, in 2019 has paved the way for further advancements in genome-edited precision breeding. *Source* Van Vu et al. (2022)

effectors (TALEs) (Tsuboi et al. 2022). These are proteins synthesized by the bacteria Xanthomonas to prevent the transcription of genes in host plant cells. Both ZFNs and TALENs are powerful tools for genome editing, but they have some limitations. ZFNs can be expensive to design and synthesize, and TALENs can be difficult to produce in large quantities. However, both technologies have the potential to be used to improve crop yields, develop new crops with desirable traits.

Two previous GE techniques ZFNs and TALENs had limited utility by their size and specificity, which made them difficult to use in some cases. However, a new GE technique CRISPR/Cas9 (clustered regularly interspaced short palindromic repeats) emerged in 2013. It uses a protein called Cas9 to make precise cuts in DNA and provides plant breeders with the ability to make targeted sequence variations, which can lead to rapid crop improvement (Chen 2018). CRISPR/Cas9 uses site-directed nucleases (SDNs) to make precise incisions at a particular region of DNA. SDN techniques are classified into three categories: SDN-1, SDN-2, and SDN-3. The SDN-1 techniques induce single or double-stranded breaks in DNA, which can lead to the removal of a part of the DNA. Whereas, SDN-2 technique uses a small donor DNA, while SDN-3 use a much longer donor DNA template for desirable mutations (Podevin et al. 2013).

The CRISPR/Cas system is a bacterial immune system that protects against viruses and other harmful genetic elements (Hu and Li 2022). It works by using RNA to guide Cas proteins to the foreign DNA, which is then broken down. The CRISPR/Cas system is divided into two classes: Class 1 systems use multiple Cas proteins to perform interference, while Class 2 systems use a single Cas protein and a CRISPR RNA (crRNA) to perform interference (Chen 2018; Hu and Li 2022). Unlike, TALENs and ZFNs, the CRISPR/Cas system can be used to target multiple sites in the genome using multiple single guide RNAs (sgRNAs). This allows for more precise and efficient genome editing. Various approaches have been used to express multiple sgRNAs in plants. One approach is to use a polycistronic gene, which contains multiple sgRNAs separated by Csy4 recognition sites, transfer RNA sequences, and ribozyme sites (Chen 2018). The cell then processes the polycistronic gene to produce mature sgRNAs for modification. A new generation of CRISPR nucleases, called Cpf1, has been discovered. Cpf1 is able to initiate its own crRNA, which makes it an efficient system for complex genome editing in crops (Wang et al. 2017).

Plant GE has shown significant potential for targeted improvement of specific traits (Sedeek et al. 2019). It allows exact changes to be made to the genetic makeup of plants, leading to the creation of crop varieties with desired characteristics (Fig. 2). New GE tools are essential for the future of crop production, as they are more precise, robust, and easier to regulate than traditional GM crops. Several products have already been developed using the CRISPR/Cas9 system, and some countries do not consider these products to be based upon GM organisms. The US Department of Agriculture (USDA) has stated that CRISPR/Cas9-edited crops can be grown and marketed without the same regulatory processes and risk assessments that are required for GM crops (Waltz 2016). This is a significant development, as it could save millions of dollars in research and development costs, reduce the time it takes to bring new crop varieties to market, and help to address public concerns about the safety of GM foods. To date, five crops developed using CRISPR/Cas9 have been approved by the USDA without the need for GM organism regulation (Jaganathan et al. 2018). These include:

- Browning-resistant mushrooms, which were created by knocking out the polyphenol oxidase (PPO) gene.
- Waxy corn plants with enhanced amylopectin, which were created by inactivating the endogenous waxy gene (Wx1).

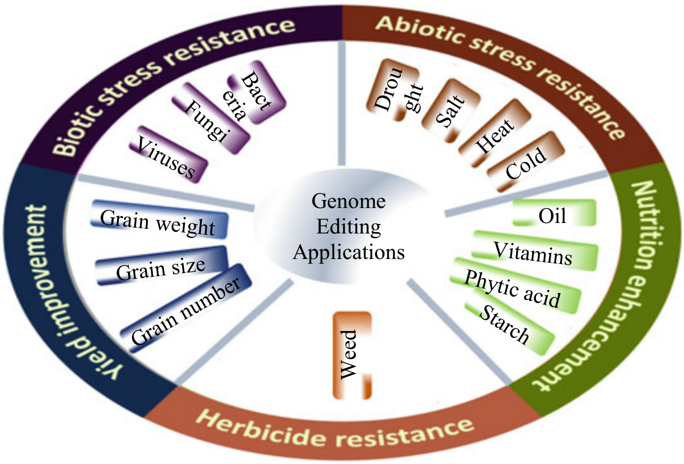


**Fig. 2** The application of plant genome editing techniques for the purpose of targeted trait improvement. *Source* Sedeek et al. (2019)

- *Setaria viridis* with a delayed flowering period, which was achieved by deactivating the *S. viridis* homolog of the corn ID1 gene.
- Camelina with improved oil content.
- Soybean with modified Drb2a and Drb2b genes for drought tolerance.

These early successes demonstrate the potential of CRISPR/Cas9 technology to revolutionize the food industry. As the technology continues to develop, it is likely that we will see even more innovative and beneficial applications in the years to come (Kumar et al. 2020).

## *2.5 Potential Benefits of Genetically Modified Crops*

### 2.5.1 Human Health

Genetically modified crops have been extensively debated regarding their benefits and risks. Barton and Dracup (2000) recognized that GM crops offer several potential benefits that cannot be ignored. These benefits include increased crop yields, enhanced nutritional content, improved resistance to pests, diseases, and environmental stressors, and reduced dependence on chemical pesticides and herbicides (Roberts and Mattoo 2018). These benefits could potentially help alleviate issues with food security, enhance agricultural output, and promote sustainable farming practices. Nevertheless, the implementation of GM products has sparked public debate, scientific evaluation, and media scrutiny concerning their appropriateness for human consumption (Raza et al. 2021). While there is no agreement on the possible consequences of GM organisms, their effect on human health remains uncertain, particularly in light of globalization. Health concerns could potentially affect individuals' acceptance of GM foods, with health-conscious people having more negative opinions of GM organisms compared to those who do not prioritize health concerns (Atalan-Helicke 2020; Weir 2019). Consumers are worried about the potential negative effects of consuming GM foods on their overall health and the perceived unreliability of these products because of their supposed long-term health and environmental consequences. The perception of genetic modification as an unnatural process affects the extent of approval of GM foods, according to Lefebvre et al. (2019).

The production of transgenic products involves technology that poses potential hazards and obstacles, which may be either familiar or unfamiliar (Tuorila and Hartmann 2020). In the early stages of this technology, concerns were raised about the possibility of unintended and hazardous changes resulting from mutations during the gene transfer and genetic modification process (Singer et al. 2021; Vega Rodríguez et al. 2022). The impact of these genetic products on human and environmental health raises concerns about labelling, food security, poverty reduction, and environmental preservation (Ramankutty et al. 2018). Research in immunotoxicology focused on transgenic products or foreign gene-expressed proteins has sparked concerns. However, the World Health Organization (WHO) maintains that technology should provide benefits to human beings by reducing allergenicity and increasing the efficiency and efficacy of food items. Several studies, such as those by De Santis et al. (2018), Kuiper et al. (2001), and Ormandy et al. (2011), support this view. It is crucial to conduct a comprehensive evaluation of all technologies employed in the food production process to ensure that food safety, public health, and environmental concerns are appropriately addressed. Several studies, including those by Galvez et al. (2018), Henchion et al. (2017), Tian (2017), and WHO (2022), have emphasized the significance of this endeavor.

This topic intends to clear up misunderstandings that exist in ongoing debates about GM crops and foods, specifically in relation to concerns about their potential effects on human health and the environment. Additionally, it examines how the seed-producing industries affect the socioeconomic status of small-scale farmers, a topic that often goes unnoticed in many reviews.

Consumers in Asian and European regions face challenges when it comes to accepting GM products. Their concerns are focused on the potential impact on human health, ethical and religious issues related to animal genes present in GM foods, and the need for proper labelling and regulations. This is discussed in studies by Bawa and Anilakumar (2013), Montossi et al. (2013), and Omobowale et al. (2009). While some consumers may still see GM products as a solution to global food safety issues and acknowledge their potential benefits, the acceptability of such products is now a topic of discussion among the academic and industrial circles globally, including studies by Andrée (2002), Frewer (2003), Lucht (2015), and Wilks and Phillips (2017).

The nutritional value of food products derived from plants is influenced by several factors, such as the presence of essential nutrients and phytochemicals, as well as the absence of antinutrients and nonessential minerals as confirmed by Parveen et al. (2022) and Raja et al. (2022). Genetic engineering methods can be used to modify crops accurately, to create new types with even more nutritional advantages, enhanced storage properties, and better organoleptic qualities, according to Miladinovic et al. (2021) and Osmond and Colombo (2019). For example, waxy corn has been genetically modified through the deletion of the endogenous waxy gene Wx1. This modification has resulted in an increased concentration of amylopectin and a decreased level of amylose, which enhances the freeze–thaw characteristics of frozen food and gives canned food a creamier texture (Duensing et al. 2018; Yadav et al. 2021; Young et al. 2022). Effective weed management is crucial in agriculture, and two common methods used are herbicide application and genetic engineering. However, herbicides can have harmful environmental and health effects, while genetically engineered (GE) crops that are herbicide-tolerant can effectively target and eliminate weeds, resulting in significant cost savings associated with weed management (Anderson et al. 2019).

Functional foods are believed to have medicinal properties and are used as therapeutic agents to improve physiological functions and treat certain ailments (Lobo et al. 2010; Swami et al. 2012; Younas et al. 2020). These foods are consumed as a regular part of the diet and may include items such as chocolate, certain types of yogurt, and cheese, among others (Damián et al. 2022; Jędrusek-Golińska et al. 2020). Functional foods are being developed to meet the needs of specific age groups or individuals with particular health conditions such as obesity or diabetes, as well as those with genetic variations (da Fonseca et al. 2017; Lascar et al. 2018; Sarma et al. 2021). Nevertheless, GM foods could potentially have harmful effects on human health. Certain food items can trigger a variety of effects, and modifications made to the genes in GM foods generally involve adding transgenes that encode enzymes capable of altering specific biochemical pathways (Tuteja et al. 2012; Breyer et al. 2014; Cockburn 2002; Krimsky 2019). When a new enzyme appears in an organism, it has the potential to deplete its corresponding substrates, accumulate its resulting products, and cause changes in the concentrations of certain biochemical compounds (Bawa and Anilakumar 2013; Lewinsohn and Gijzen 2009; Prosser et al. 2014) These types of behaviors may not be well tolerated and could lead to the accumulation of toxins within the body. Such toxic buildup has been noted in studies by Lu et al. (2010), Peake et al. (2015), and Schildknecht et al. (2013). Moreover, it's important to note that secondary metabolites derived from plant sources can be toxic to humans. For instance, steroidal glycoalkaloids found in the skin of green potatoes, as researched by Alamgir and Alamgir (2018) and Fogelman et al. (2019), can have harmful effects. When present in high concentrations, this compound can cause gastrointestinal discomfort in humans, as observed in studies by Borchers et al. (2010) and Haque et al. (2020).

Most studies indicate that the majority of individuals have negative perceptions of GM foods, with concerns about potential hazards to human health and adverse impacts on genetic makeup (Hu et al. 2020; Royzman et al. 2020; Scott et al. 2018). These concerns are particularly prevalent in Europe and developing countries due to inadequate labelling and regulatory policies (Sulis et al. 2022; Viera et al.

2020). Consumers are generally curious about the food they consume, including its origin, processing techniques, and additional ingredients (Ardoin and Prinyawiwatkul 2021). Novel concepts in food production systems can make consumers hesitant to buy recently introduced food items such as GM products (Siegrist and Hartmann 2020; Wunderlich et al. 2018).

Continued research and regulation are necessary to ensure the safety of GM foods and mitigate potential health risks. The production of GM food is seen as necessary to meet the increasing demand for food due to the growing global population. However, the infiltration of GM foods into the food supply has sparked heightened levels of apprehension and discourse regarding their safety. The public's understanding of GM foods and their potential health risks is crucial in shaping policy decisions and regulatory frameworks. While the conclusion derived from the scientific method is typically regarded as an accurate representation of reality, cultural and attitudinal variations may impact public perception and understanding. According to research by Yormirzoev et al. (2018) and Burke et al. (2020), 63.6% of participants considered fruits and vegetables to be the most susceptible to genetic modification, while 39.8% believed canned food was the most susceptible. However, all types of food are susceptible to genetic engineering. Regulation (EC) No 1829/2003, applicable to all 27 EU Member States, aims to ensure a superior standard of safeguarding human, animal, and environmental well-being in relation to GM food and feed (EFSA 2022).The consumption of substances, whether they are natural or man-made, has an impact on human health. The development of GM products has sparked public debate and scientific discussion about the potential risks involved (Chen 2018). Some people prioritize their health and hold negative opinions about GM foods, while others do not. Certain consumers have concerns about the potential negative effects on their overall health and question the reliability of GM foods (Zhang et al. 2016; Oselinsky et al. 2021). The level of acceptance of GM foods is influenced by the extent to which they are seen as natural, as many consumers consider genetic modification to be unnatural (Loebnitz and Grunert 2018; Jin et al. 2022).

### 2.5.2 Environmental Impact

The adoption of GM crops has the potential to deal with challenges related to ensuring food security, enhance agricultural productivity, as well as contribute to sustainable farming practices. Additionally, GM crops also possess the ability to reduce environmental impacts associated with conventional farming methods. For example, GM plants that have innate resistance to particular pests can lessen the demand for chemical insecticides, thus decreasing environmental contamination (Mondelaers et al. 2009). Moreover, some GM crops can be engineered to endure specific herbicides, which allows farmers to use more environmentally friendly weed management strategies (Green and Owen 2011). By minimizing the use of chemicals, GM crops can contribute to preserving biodiversity, soil health, and water quality (Raymond Park et al. 2011). Moreover, GM crops can offer sizeable economic benefits to farmers. Increased crop yields and improved resistance to diseases and pests can help farmers increase their incomes. This can assist them in overcoming challenges such as fluctuating market prices and agricultural losses (Kavhiza et al. 2022). In addition, GM crops can result in cost savings and increased operational efficiency for farmers by reducing the need for daily monitoring and spraying of crops (Sharma et al. 2022). Although these benefits are recognized, Conner et al. (2003) emphasize the need for independent regulation and thorough environmental impact assessments. It is crucial to assess the potential risks of GM crops to ensure their safe deployment and minimize any adverse effects on the environment and human health (Kumar et al. 2020).

One of the main risks associated with GM crops is the possibility of genes escaping and being transferred to wild or weedy relatives through hybridization (Chen et al. 2004; Lu and Yang 2009; Warwick et al. 2009). This gene flow can have unintended consequences on the environment, such as the creation of herbicide-resistant weeds or the alteration of natural ecosystems. To effectively manage these risks, it is necessary to evaluate the biology of the plant and its interaction with the environment (Malekmohammadi and Blouchi 2014; Van den Brink et al. 2016). This involves promoting transparency and establishing mechanisms for informed public participation in decision-making related to the cultivation and commercialization of GM crops. Addressing concerns is also crucial (Harfouche et al. 2021).

In the past decade, there has been significant attention and adoption of GM crops worldwide. The global biotech crop areas have seen a double-digit growth rate. These crops now cover over 90 million ha and are planted by over 8.5 million farmers in 21 countries (Jha et al. 2020). The benefits for farmers include reduced spraying and monitoring efforts, leading to economic advantages. However, the public perception of GM crops varies across regions. There is a more positive attitude in the Americas compared to Europe, where scientific evidence plays a crucial role. In Europe, the release of GM crops into the environment is subject to meticulous evaluation according to Directive 2001/18/EC, also known as the Cultivation Directive (Sanvido et al. 2012). The European Food Safety Authority (EFSA) has a significant role in evaluating the safety of new GM organisms and advising risk managers in Europe. In order to improve the reliability and usefulness of environmental risk assessments (ERAs) for GM plants problem formulation is crucial. GM crops have many advantages, including higher crop yields, better nutritional value, increased resistance to pests and diseases, and decreased dependence on chemical inputs (Barton and Dracup 2000). These benefits can help address food security concerns, improve agricultural productivity, and encourage sustainable farming practices. Additionally, GM crops can have positive economic effects for farmers, including higher incomes and reduced costs due to less need for spraying and monitoring.

To ensure the relevance of environmental risk assessments (ERAs) for GM crops, Wolt et al. (2010) proposed a common framework that emphasizes the importance of producing an analysis plan. Similarly, Kuzma (2021) introduced the procedurally robust risk assessment framework (PRRAF) to enhance risk assessment protocols for genetically engineered organisms in situations of high uncertainty. These frameworks offer principles and criteria to guide risk assessment processes and aid in decision-making. In 2012, Sanvido et al. provided guidance to European risk managers on defining measurable indicators and parameters for the environmental safety assessment of GM crops. Their approach highlights the need to protect specific ecological entities and attributes, as well as establish precise thresholds for potential harm. Furthermore, they advocate for assessing both the risks and benefits associated with GM crops. In 2011, Hilbeck et al. presented an improved system-oriented approach to environmental risk assessment (ERA) for GM plants, addressing deficiencies observed in the existing approach. Their concept places the GM plant at the center and incorporates a hierarchical testing scheme from laboratory studies to field trials. They also advocate for the inclusion of testing organisms from the receiving environment and provide case examples for different crop scenario in 2017, Tsatsakis and colleagues conducted a thorough evaluation of the environmental effects of GM crops, with a focus on associated risks and concerns regarding biosafety. Although certain negative consequences have been observed, such as alterations in crop prevalence, increased tolerance to herbicides and insecticides, and disturbances to biodiversity, the consumption of GM plant products as a whole is believed to be safe. The evaluation emphasizes the need for analyses to weigh the risks and benefits of GM crop implementation, in order to determine their potential impacts on human, animal, and environmental health.

# 3 Socioeconomics of Genetically Modified Food

## *3.1 Social Aspects*

Advancements in technology have improved food production and allowed for better nutrition and greater diversity in consumer demands. However, it is important for food companies, policymakers, and regulators to understand the public's response to genetic modification technology in food production, particularly in developing countries (Azadi and Ho 2010). Consumer attitudes towards GM foods are influenced by their behavior, beliefs, perspectives, and opinions on the perceived unnaturalness and artificiality of these foods (Pattanapomgthorn et al. 2020). Therefore, it is necessary to examine social factors that affect consumer behavior towards GM foods, including their perception of risks, attitudes towards acceptance, and demand for information.

A noteworthy portion of the general population is uncertain about consuming GM foods, and lack knowledge on the topic. Consumer attitudes towards GM foods vary globally, with Europeans and Chinese consumers exhibiting a preference for conventional food and hesitancy to purchase GM foods. Consumers lacking knowledge about GM technology generally avoid purchasing GM foods, whereas those with knowledge often acquire information from online sources and social media. Safety concerns related to GM foods have sparked debates and led to varying consumer perceptions, as revealed by a survey conducted by Azlin et al (2020). Participants in the survey expressed concern about potential hazards associated with GM foods and believed that perceived risks outweighed advantages (Li and Bautista 2019).

However, scientific knowledge on GM foods is generally higher among experts than the general population, with scientific research considered the ultimate truth. A significant portion of the population emphasizes the importance of labelling GM foods and conducting allergy testing, as highlighted by Singhal (2018). According to a study by Shami (2022), a substantial majority (74.3%) of respondents in an online survey were aware of GM foods, with approximately 43.7% believing that perceived risks were associated with GM foods on human health and the environment. The majority of respondents considered the risks of GM foods to outweigh their benefits, with some participants expressing concerns about potential effects on their genes resulting from consuming GM foods, but the specific nature of these effects remains unknown. The study underscored the disparity between expert knowledge and public opinions regarding GM foods, with scientific findings generally perceived as more reliable but influenced by cultural and attitudinal factors.

### *3.2 Consumer Perception*

Despite the potential benefits of GM foods and other biotechnologies, there is a significant amount of consumer opposition to them. This opposition is often based on moral concerns rather than a rational evaluation of the science. Consumer perceptions of GM food are complex and vary widely, linked to their awareness and knowledge of GM food, their lifestyles, and current global trends. According to the Food Safety report (2019), Europeans have a high level of awareness of food safety issues. For example, 72% of Europeans have heard about food and drink additives such as colors, preservatives, and flavorings. In Sweden, the Netherlands, and Estonia, even more people are aware of these additives, with 98%, 95%, and 87% of respondents, respectively, saying they have heard about them. Interestingly, while 60% of Europeans have heard about GM ingredients in foods or drinks, only 21% have heard about genome editing. In Poland, these numbers are even lower, with 58% and 16%, respectively. Swedes are the most likely to have heard about GM ingredients in food and drinks (83%), while Finns (62%) and Estonians (57%) are the most aware of genome editing. In terms of socio-economic factors, it is worth noting that people who have heard about GM ingredients in food and drinks are more likely to be adults (20 + years old) and to be self-employed or managers. Overall, this research suggests that Europeans have a high level of awareness of food safety issues, including GM food. However, there are some differences in awareness across countries, as well as in terms of socio-economic factors.

A survey in the UK found that 70% of people believe that genetic modification of foods is morally wrong, while in the US, the figure is 45% (Rzymski and Krolczyk 2016). However, public concern about this issue seems to have increased in recent years. In a survey Woźniak-Gientka et al. (2022) found that 62% of the Polish population opposed the adoption of GM foods due to their belief these can be harmful to public health. Similar concerns can be found all over the world in the consumers for accepted GM foods to be included in their daily diet (Lassoued et al. 2019; Kubisz et al. 2021; Woźniak et al. 2021). The Saudi public is more concerned about the potential risks of GM foods than experts. A survey found that 93% of Saudis believe that GM foods could be harmful to human health, and 85% believe that they could cause genetic mutations (Shami 2022).

In another public survey, the majority of respondents (82.5%) believe that GM foods are developed for profit rather than human health (Cross et al. 2021).

A study conducted by Royzman et al. (2020) revealed that a majority of participants expressed uncertainty and lack of knowledge about GM foods and declined to purchase them. The study also found that there is a high level of favorable attitude toward natural foods that have not undergone genetic modification. Food labelling policies vary across nations. The US and Canada exhibit more flexibility toward GM foods and enforce no mandate for labelling. In these countries, companies are responsible for testing new GM food products. In contrast, European Union member states exhibit greater apprehension toward GM foods and mandate labelling for any food product containing even a minimal amount of GM material (Sendhil et al. 2022).

The opinions that consumers hold regarding the safety risks associated with GM products have a significant impact on their attitudes. These opinions may be influenced by factors such as their level of knowledge, societal beliefs, expectations regarding health, ideas of what is natural, and inadequate labelling. Previous research has demonstrated that individuals who prioritize the potential negative consequences of GM foods tend to have negative attitudes toward them, while those with greater knowledge generally hold positive opinions (Siegrist and Hartmann 2020; Vecchione et al. 2015). Trust is crucial in shaping how new technologies are perceived and adopted, particularly for individuals who do not have a lot of information about these technologies. Social trust has been shown to be a powerful force that can guide consumers towards embracing novel technologies, including GM organisms. Experts in the field have conducted empirical investigations that support this approach (Vindigni et al. 2022). Conversely, GM crops and food can have a positive impact on the socio-economic status of farmers in developing countries, and the negative impact on the environment and human health is minimal, while numerous benefits are provided (Li et al. 2014). It is necessary to make efforts that help to bridge the gap between expert knowledge and public perception by taking into account factors such as cultural and attitudinal diversity (Shami 2022).

These studies suggest that public opposition to GM foods and other biotechnologies is often based on moral concerns rather than a rational evaluation of the science. This opposition is likely to continue until there is greater public understanding of these technologies and their potential risks and benefits. These factors all contribute to the public's opposition to biotechnology. It is important to address these concerns in order to build public acceptance of this new technology. These concerns are similar to those held by people in other countries, such as the European Union and developing nations. The main reasons for these concerns are the lack of adequate labelling and regulatory oversight of GM foods, as well as the potential for allergic reactions, the depletion of agricultural diversity, and the emergence of antibiotic resistance

(Gruère 2006; Bawa and Anilakumar 2013; Öz et al 2018). These findings can help us to better understand how to communicate about GM food with consumers in Europe.

### *3.3 Economic Aspects*

Genetically modified crops have the potential to ensure a sustainable food supply. However, public acceptance is hindered by concerns about safety, corporations' trustworthiness, awareness, moral dilemmas, regulatory frameworks, and unintended mutations (Kedisso et al. 2022). GM crops offer potential advantages in terms of increased yields, improved resistance, and economic benefits for farmers. Applications of new technology for GM crops, such as insect resistance, have shown economic, environmental, and health benefits (Li et al. 2020). This technique provides opportunities for enhancing insect resistance and contributing to sustainable agricultural production (Krishna et al. 2022). Educating individuals about breeding techniques can help overcome these challenges. Addressing public apprehension is crucial for the adoption of GM crops, especially in developing countries facing food scarcity and rising costs (Sendhil et al. 2022). Furthermore, GM crops can have positive economic effects for farmers, including higher incomes and cost savings by reducing the need for spraying and monitoring.

## 4 Regulatory Considerations

The way in which consumers perceive and accept GM foods is influenced by a range of factors, such as concerns about safety and labelling regulations. Although there is a consensus among scientists that GM foods are safe, the opinions and worries of the public vary (Gaskell et al. 1999).

DNA-free genome editing technology reduces the likelihood of unintended mutations and off-target effects. This may help alleviate some of the safety concerns associated with GM organisms (Hartung and Schiemann 2014). However, regulatory bodies still require thorough evaluation of GM crops, including those developed using DNA-free genome editing, to ensure they comply with regulations and are safe (Turnbull et al. 2021). As DNA-free genome editing technology continues to advance, researchers are exploring new strategies and tools such as base editing and prime editing, which offer more precision and expand the scope of genetic modifications that can be achieved (Anzalone et al. 2019; Liu et al. 2020). Challenges remain, including the need to improve editing efficiency, reduce off-target effects, and address potential intellectual property and regulatory concerns (Ahmad et al. 2021). A thorough assessment is necessary to ensure the safe and responsible use of DNA-free genome editing technology in the development of GM food products. This assessment should consider technical, social, ethical, and environmental dimensions

(Gupta et al. 2021). Responsible innovation practices such as transparent communication, stakeholder engagement, and comprehensive risk assessments can guide the development and deployment of GM crops generated using DNA-free genome editing techniques.

The safety of GM foods has been thoroughly studied and regulated by different government agencies globally. Based on scientific consensus, the current GM foods available in the market are considered safe for consumption (National Academies of Sciences and Medicine 2016). Nonetheless, the varying public opinion and concerns about the safety, environmental effects, and potential socioeconomic consequences of GM foods must also be taken into account (Gaskell et al. 1999).

The assessment of the safety of GM food products is a crucial element during their development and commercialization. Regulatory bodies across the world, such as the Food and Drug Administration (FDA) in the United States and the European Food Safety Authority (EFSA) in the European Union, evaluate the safety of GM organisms using scientific evidence (EFSA 2021).

These assessments concentrate on identifying any potential risks to both human health and the environment. The way in which GM food products are labelled varies from country to country. Some countries require mandatory labelling of GM organisms, while others have regulations that are voluntary or nonexistent. The decision to label GM organisms is usually motivated by concerns related to consumer choice, transparency, and the possibility of causing allergies (Bawa and Anilakumar, 2013). The knowledge and comprehension that consumers have about GM food products have a considerable impact on shaping public perceptions and acceptance.

The European Union has regulations, such as Regulation (EC) No 1829/2003 and Directive 2001/18/EC, that are meant to ensure the safety of GM food and feed, as well as govern the cultivation of GM crops (Vega Rodríguez et al. 2022). In Saudi Arabia, the Saudi Food and Drug Authority (SFDA) works closely with regulatory bodies in other countries to make sure that imported food products meet essential safety and quality standards. The KSA Food Act (SFDA 2021) outlines provisions in Article 7 for regulating the importation of food into Saudi Arabia. This law mandates that food products undergo approval from the SFDA before they can be released, ensuring compliance with regulations, policies, and procedures outlined in the Act. The SFDA is responsible for creating regulatory bylaws that govern the clearance process for imported food in Saudi Arabia. According to Article 3, paragraph 4 of the Food Act bylaws, exporting countries must adhere to import conditions and requirements set by the SFDA when shipping their products to Saudi Arabia. The SFDA has the authority to establish these requirements to ensure that imported food products meet essential safety and quality standards before entering the Saudi Arabian market. This regulatory framework is in place to protect the health and well-being of consumers in Saudi Arabia by making sure that their food products comply with necessary safety and quality standards. A mandate has been established that compels the labelling of nearly all GM foods.

The labelling threshold has been set at a genetically engineered content of 0.9–1%. The term "threshold" refers to the highest permitted genetic engineering content per ingredient contained in each food item. This information is sourced from the

Center for Food Safety's GE Food Labelling Laws and is illustrated in Fig. 1. The regulations and policies regarding labelling of GM foods vary between different countries. The US and Canada allow for more flexibility, as companies can test the safety of their own products and the Food and Drug Administration (FDA) does not mandate labelling (Hamburger 2019). On the other hand, European Union (EU) member states are more concerned about environmental impact and require labelling on any food products that contain GM materials, regardless of the amount (Sendhil et al. 2022). In Norway, the focus is on evaluating the societal benefits, sustainability, and ethical aspects of limited cultivation and importation of GM crops (Myskja and Myhr 2020). Recently, there have been discussions about how the EU GMO Directive should be interpreted, which may result in different treatment of identical products based on their technology (Menz et al. 2020).

As the global population continues to grow, production of GM foods plays an important role in meeting our nutritional needs. However, ensuring consumer safety and addressing perceived risks are crucial in determining whether these foods will be accepted (Raza et al. 2021). Before introducing genome-edited plant products into the market, regulatory agencies must establish clear policies and procedures (Yang 2022). The level of acceptance of GM products among consumers remains a topic of interest in both industrial and academic circles (Oteh et al. 2020). In an Islamic legal context, it is necessary to ensure that modern biotechnology is appropriately used in the production of GM foods, and that they adhere to halal guidelines and are safe for human consumption (Erol 2021). Moreover, it is important to consider uncertainties in the production process and the feasibility of implementing precautionary measures. This chapter proposes an interdisciplinary approach that incorporates Islamic legal methodology to address the topic of GM products. Its goal is to promote halal nutrition and improve the quality of life for all people, regardless of their religious beliefs (Erol 2021). While Islamic law lacks conclusive provisions on these matters, they can be effectively evaluated using the principles of maslahah (public interest) and maqasid (objectives of Islamic law) to promote righteousness and prevent harm.

The SFDA has the authority to ask the relevant authority in the exporting country for official guarantees about the use and regulation of certain chemicals used in making food products of plant origin (SFDA 2021).

The process of creating GM food involves several stages, such as extracting or synthesizing genes and inserting them into the desired genetic location. In the United States, regulatory measures ensure the safety of GM foods for human consumption. It is important to note that contemporary food products are subject to more rigorous standards than in earlier times. Regulatory agencies in the US, such as the FDA, EPA, and USDA, evaluate newly developed GM crop plant products (Entine et al. 2021). The APHIS ensures the safety of GM plants for the ecosystem, and GM plants are classified as regulated or non-regulated (Zetterberg and Edvardsson Björnberg 2017). Non-regulated status is granted to GM plant varieties that lack foreign DNA from plant pests, and the FDA evaluates the safety of GM food items for consumption. A few gene-edited commodities, including Calyno™ soybean oil, SU Canola™, and waxy corn, have been introduced into the market.

Wolt and Wolf's (2018) work provides a comprehensive examination of regulations concerning genome editing in the US. Regulation (EC) No 1829/2003 applies to all 27 Member States of the European Union and concerns GM food and feed produced from GM organisms (EFSA 2013). The objective of the regulation is to ensure that the authorization processes for GM food and feed achieve a high degree of protection for human, animal and environmental well-being. The regulation applies to food and feed commodities, as well as their imports, with Regulation 1830/2003 governing the tracing and identification of GM products (Deckers et al. 2022). The Cultivation Directive, which involves the intentional release of GM organisms into the environment, is a decision made by Member States in accordance with Directive 2001/18/EC, including the cultivation of GM crops (Francescon 2001). This tool allows for the cultivation of GM crops and flora, subject to a thorough evaluation of their potential negative impacts on human well-being and the ecosystem (Potts et al. 2016).

## 5 Monitoring of Genetically Modified Food in Saudi Arabia

It is essential to monitor GM food in Saudi Arabia to ensure compliance with established safety guidelines and regulations. The role of GM organisms in food and nutritional security is critical, particularly for the growing population. The overall goal in Saudi Arabia is to develop a sustainable, cost-effective, and reliable agricultural system that can contribute to global food security. Several regulations have been established worldwide to monitor the presence of GM food in markets. These regulations include labelling and traceability of GM organisms and food products produced from GM organisms, screening measures at regular intervals, and controlling the deliberate release of GM organisms into the environment. Additionally, reliable techniques for detecting and quantifying GM food have been developed to label food accurately (Abdel-Mawgood et al. 2010).

The screening method is a rapid technique that provides information about the presence or absence of GM organism products. The most convenient, reliable, and sensitive techniques for detecting and quantifying GM organisms are the polymerase chain reaction (PCR) and enzyme-linked immunosorbent assay (ELIZA) techniques, as described by Holst-Jensen et al. (2003). PCR and ELIZA techniques can readily identify DNA and protein from GM organism products, respectively. However, for GM organism quantification, quantitative real-time PCR is preferred over the conventional PCR method. Promising new techniques for more precise detection and quantification of GM organisms include next-generation sequencing, capillary gel electrophoresis, microarray, and digital PCR, as detailed by Salisu et al. (2017).

In Saudi Arabia, cultivating GM plants is not common due to a ban on GM seed imports by the Ministry of Environment, Water, and Agriculture (MEWA) since 2004. However, GM food and food products are allowed to be imported with labelling if their content of GM organism elements exceeds one percent (Hallman 2020). A survey was conducted to determine the presence of GM food in Saudi markets, which found that out of 202 food samples, 20 were positive and non-compliant with Saudi regulations, indicating the effectiveness of Saudi's stringent legislation on GM food products (Abdel-Mawgood et al. 2010). On the other hand, a study conducted in Riyadh food markets on meat products found that about 43% of the tested products contained GM soybean, although the percentage was less than 0.1%. The addition of soybean to meat products was not labelled, which contradicts consumer rights and is considered to be commercial deception/adulteration (Aljabryn 2022).

## *5.1 Bioethical Issues Assessment of Genetically Modified Foods in Saudi Arabia*

The use of GM organisms has become increasingly common in the production of food crops around the world. While this technology has the potential to address issues related to food security, it also raises bioethical concerns for consumers, particularly Muslims. The Islamic perspective on GM organisms is complex and goes beyond simply determining whether or not a food is halal (permissible). Under the Maqasid al-Shari'ah (the objectives of Islamic law), even if a food is halal, it cannot be permitted if the process used to obtain it is unethical (Idris et al. 2020). For example, if a GM organism food is produced using a process that harms the environment or violates the rights of workers, it would be considered haram (impermissible) under Islamic law. Ultimately, the Islamic perspective on GM organisms is one of caution and discernment (Erol 2021). While there is potential for this technology to benefit society, it is important to ensure that it is used in a way that is ethical and in accordance with Islamic values.

The GM organisms are created by inserting genes from one organism into another. This process can be used to create crops that are resistant to pests, herbicides, or diseases. However, it has also raised concerns about the safety of GM organisms, as the new genetic material could potentially be harmful to humans or the environment. One concern is that GM organisms could transfer their modified genes to other organisms, such as wild plants or animals. This could lead to the creation of new species that do not exist in nature, and whose impact on the environment is unknown. For example, GM organism crops that are resistant to herbicides could lead to the development of "superweeds" that are even more difficult to control. Another concern is that GM organisms could have negative health effects on humans. Some studies have shown that GM organisms can cause allergic reactions or other health problems. However, more research is needed to determine the long-term effects of GM organisms on human health. The use of GM organisms is a complex issue with no easy answers. On the one hand, GM organisms have the potential to increase crop yields and reduce food waste. On the other hand, there are concerns about the safety of GM organisms and their impact on the environment. More research is needed to address these concerns and to determine whether the benefits of GM organisms outweigh the risks.

In Muslim societies, there is a growing interest in bioethics and food ethics. This interest is shifting from a focus on food consumption to food production. This shift is in line with the fundamentals of Islam, which emphasize the importance of Aqidah (belief), syariah (law), and Akhlaq (ethics/morality) (Al-Attar 2017). These fundamentals serve as a guide for society and are relevant to the whole of human life. The growing interest in bioethics and food ethics in Muslim societies is a positive development. It shows that Muslims are concerned about the ethical implications of scientific advances and the way that food is produced (Erol 2021; Khattak et al. 2011). Such concerns are in line with the teachings of Islam, which emphasize the importance of protecting human life and treating all living things with respect. Therefore, it is essential to conduct comprehensive evaluations of this technology to ensure that its objectives do not conflict with Islamic law and that any harmful effects on humans or the environment are avoided (Idris et al. 2020).

There is no global standard for labelling GM foods, which can complicate international trade. In some countries, such as the United States, Canada, Japan, the Philippines, Thailand, and Taiwan, food with up to 5% GM content does not need to be labelled. However, in other countries, such as Saudi Arabia, Brazil, Australia, and New Zealand, food with any GM content must be labelled (Premanandh et al. 2012). This lack of harmonization can make it difficult for companies to export GM foods, as they must comply with the labelling requirements of each country they wish to sell to. The lack of a global standard for GM food labelling is due to a number of factors, including:

- Different countries have different levels of public acceptance of GM foods.
- There is still some scientific uncertainty about the safety of GM foods.
- Some countries are concerned about the potential for GM foods to harm their agricultural sectors.

Despite these challenges, there is a growing movement towards harmonization of GM food labelling standards. In 2015, the Codex Alimentarius Commission, a global food standards body, adopted guidelines for the labelling of GM foods. These guidelines are not legally binding, but they provide a framework for countries to develop their own labelling standards. The harmonization of GM food labelling standards would make it easier for companies to export GM foods and would help to ensure that consumers have accurate information about the food they are buying. Labelling of GM foods is important for the public good, or maslahah, because it allows consumers to make informed choices about what they eat. While some biotechnology companies may oppose labelling, research shows that the majority of consumers want GM foods to be labelled. For example, surveys in the United States, Spain, and Europe have shown that the majority of people in these countries favor labelling of GM foods (Wenner 2018). The importance of labelling GM foods is similar to the importance of labelling halal foods. Halal foods are those that are permissible to eat according to Islamic law. Both distributors and customers of halal foods check whether the food is halal and prefer products with halal certification. This shows that consumers have a right to know what is in the food they eat and how it was produced. Therefore, it is in the public good to label GM foods. This would allow consumers to make informed choices about what they eat and would protect their right to know what is in their food.

In 2001, Saudi Arabia banned products from Europe because there was a suspicion that the animals used to produce those products had been fed prohibited animal parts (Khattak et al. 2011). This was in line with the Islamic principle of avoiding anything that is considered haram, or forbidden. The ban shows that Islamic authorities take even the slightest suspicion of haram ingredients seriously, in order to protect the faith. In a more recent study in Saudi Arabia, Shami (2022) reported that the majority of respondents believed that the risks of GM foods outweigh the benefits. Regional studies have shown that consumers in Saudi Arabia and the United Arab Emirates (UAE) have unknowingly consumed foods containing GM substances. This is because GM foods are not labelled in these countries. Different market-oriented studies reported an alarmingly high number of GMFs in Arab markets (Aljabryn 2022; Bakr and Ayinde 2013; Premanandh et al. 2012). The findings of these studies suggest that a significant number of consumers in Saudi Arabia and the UAE are unknowingly consuming GM foods. This is because GM foods are not labelled in these countries. In 2005, Saudi Arabia approved the import of GM foods for human consumption. However, the approval did not include GM animal products, dates, grains and seeds, or ornamental plants. GM foods imported into Saudi Arabia must be clearly labelled in both Arabic and English, and must be certified as safe for human consumption in their country of origin (Aljabryn 2022). The Saudi government has taken some steps to address the issue of GM food labelling. In 2017, SFDA issued a new regulation requiring all GM foods to be labelled with a clear and visible label. However, it is still unclear how effective this regulation will be in ensuring that GM foods are properly labelled.

## 6 Role of Genetically Modified Foods in Food and Nutritional Security

Adequate sources of food must provide enough calories and essential nutrients to support life. However, food insecurity is a significant threat to individuals globally, particularly with the projected population of 8.3 billion by 2030. Challenges such as climate change, less arable land, and emerging diseases exacerbate the issue of food security. To ensure food security, crop production must double (Godfray et al. 2010; Jones 2017). Plant breeders use natural and artificial mutations and strategic breeding for hybrid vigor, but further efforts are necessary to address existing and future obstacles.

Biotechnology, which includes genetic engineering, is essential for maintaining food security, boosting productivity, and creating functional foods (Babar et al. 2020). GM crops are capable of increasing agricultural production by creating strains that can withstand biotic and abiotic stresses, increasing yield, and fulfilling the global food demand (Muzhinji and Ntuli 2021). Moreover, breeding techniques and genetic engineering can be used to enhance the nutritional value of crops, thereby addressing nutrient deficiencies and improving individual health outcomes (Elemike et al. 2019). The development of high-yield, resilient, and nutritious crop varieties is essential due to challenges such as food insecurity, population growth, and limited arable land availability (Godfray et al. 2010; Jones 2017). While genetic engineering is necessary to address these challenges, concerns remain regarding health and environmental risks (Qaim 2020). These developments can enhance global food production and security, as well as address issues of food scarcity, ensuring better access to nutritious food for populations worldwide (Muzhinji and Ntuli 2021).

European consumers are particularly concerned about food security, origin, and quality, and they prefer natural production methods (Oravecz et al. 2020; Saraiva et al. 2020). Educating individuals about the differences between GM and genetically engineered crops, as well as the advantages and disadvantages of various breeding techniques, may help address these concerns (Gremmen et al. 2019). To respect religious beliefs, GM foods have been developed using natural resources, with the goal of enhancing food security and improving the quality of life for consumers.

The creation of GM products poses potential risks and challenges that may or may not be acknowledged. Issues about the effect of genetic products on both human and environmental health primarily center around labelling, ensuring food security, reducing poverty, and preserving the environment (Ramankutty et al. 2018). Studies on the immunological effects of GM products or proteins created by foreign genes have raised concerns, but the World Health Organization maintains that technology should bring benefits to humanity.

## 7 Conclusion and Prospects

Genetically modified food has been a topic of debate and controversy for quite some time. The modern technologies used in breeding food crops have both potential benefits and socio-economic implications. Although conventional breeding methods are still used, their limitations make genetic engineering an attractive alternative to improve crop productivity and nutritional value. GM food products have promising health benefits, are environmentally friendly and contribute to food security goals by providing higher yields. However, ethical concerns and public perception of GM food raise questions about the safety of these products and their potential environmental impact. There is also a need for transparent regulations to ensure biosafety, monitor production, and protect consumers.

Undoubtedly, GM food is a potentially significant tool in agriculture as it has the potential to combat increasing food demand and sustain environmental pressure. However, its implementation requires a cautious approach that includes collaboration with relevant stakeholders, developing regulatory frameworks and enhancing public engagement to achieve desired socio-economic and health benefits. Saudi Arabia is working to develop its GM food technologies and has invested resources in researching crop breeding and biotechnology innovations. However, there are challenges, including low public awareness and perception of GM food applications. The country needs to put in place essential measures that include biosafety procedures, regulations, and public awareness campaigns to ensure safe and acceptable GM food products. The deployment of GM food into improved food marketplaces should be complemented by sufficient consumer safety measures. These steps would permit for a reduction in customer perception threat by paying extra attention to the data presented, specifically relevant to health. Concern about health is, after all, the most powerful element in consumer perception of risk from these foods. The issue of GM food labelling is a complex one, and there is no easy solution. However, it is important to ensure that consumers have access to accurate information about the foods they are eating. The Saudi government should continue to take steps to improve the labelling of GM foods in the country.

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# Chapter 17
# Utilization of Edible Insects as Food and Feed with Emphasis on the Red Palm Weevil

**Hamadttu Abdel Farag El-Shafie**

**Abstract** Traditionally, over 2000 edible insect species are utilized as food in Africa, Asia, and South America. Edible insects as novel food can meet the amino acid requirement for humans and thus contribute very much in the global food security. Entomophagy is not a new and it has been practiced for a long time ago. The Food and Agriculture Organization (FAO) of the United Nations is advocating the use of edible insects as an alternative to conventional sources of proteins for alleviating malnutrition and enhancing the livelihood of poor communities. The reasons are that edible insects have high feed conversion ratios, require less space for farming, need low investment capital, and emit low level of greenhouse gases. So far, the European commission authorized four insect species as novel food for humans and as animal feed in the European Union. These are the yellow mealworm *Tenebrio molitor* L., the house cricket *Acheta domesticus* (L.), the migratory locust *Locusta migratoria* (L.) and the lesser mealworm *Alphitobium diaperinus* (Panzer). The European Food safety Authority assessed them as safe for human consumption. This chapter summarizes the reasons favoring the consumption of insects, their nutritional composition, farming and mass rearing, harvesting from the wild and legislative measures of commercialization and processing.

**Keywords** Novel food · Entomophagy · Food security · Nutrition · Edible insects · Micro-livestock

H. A. F. El-Shafie (✉)
Date Palm Research Center of Excellence, King Faisal University, 31982, Al-Ahsa, Saudi Arabia
e-mail: helshafie@kfu.edu.sa

Department of Crop Protection, Faculty of Agriculture, University of Khartoum, Khartoum North, Shambat 13314, Sudan

 
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## 1 Introduction

Insects belong to the phylum Arthropoda, subphylum Hexapoda and class Insecta. They are more diverse and numerous among living organisms on earth due to their relatively small size, adaptability to different environmental conditions, mobility, and high reproductive ability. Approximately, more than 5 million species of insects exist worldwide making up the largest percentages of terrestrial animals' biomass (Losey and Vaughan 2006). However, the known described species are around 1 million (Stork 2018). Insects play an important role in sustainable agriculture through provision of essential ecosystem services including pollination of economic crops, decomposition of organic matter, dispersal of seeds, soil regeneration, nutrient cycling, and biological control. Insects particularly acridids represent a natural source of food for many vertebrates including birds, fish, lizards, snakes and amphibians (Anand et al. 2008). Additionally, insects serve as bio-indicators, and provide an essential source of non-conventional human food and animal feed. Globally, the number of insects utilized by humans as food ranges between 1900 and 2141 species (van Huis 2013; Jongema 2020). The fast growing of the world population and scarcity of resources coupled with climate change necessitate the search for cheap and sustainable source of food as alternative to the conventional meat production and as feedstock (van Huis 2013; FAO 2013). The consumption of edible insects by humans and utilization as animal feed is not new and has been addressed a long time ago (Halloran et al. 2014; Tang et al. 2019). However, recently edible insects have been advocated a sustainable source of high-quality protein to alleviate malnutrition in many places of the world (van Huis 2018; FAO 2021). van Huis (2018), reported that the orders Coleoptera, Lepidoptera, Hymenoptera, Diptera, Orthoptera, Hemiptera, Isoptera, and Dipera are eaten as food with Coleoptera being the most consumed.

Insects are now consumed, as human food, in Africa, Southeast Asia, Australia and Latin America (Rumpold and Schlüter 2013). Likewise, the demand for insects as animal feed is increasing in China, South Africa, the Netherlands, USA, Canada, and Spain (Halloran et al. 2014). Insects have a high feed conversion ratios coupled with low emission of greenhouse gases (van Huis 2013). The number of people who are consuming insects worldwide may be several hundred million and the majority of these insects are naturally harvested from wild plants, forests, and field crops (van Huis et al. 2022).

Edible insects can supply a good source of high-quality proteins, fat, vitamins, fiber, minerals and carbohydrates (da Silva Lucas et al. 2020). Thus, they can contribute much in assuring global food security (van Huis 2013). In addition to consumption of edible insects by human as food (entomophagy), they are also been used in traditional medicine for healing many diseases (entomotherapy) (Devi et al. 2023). Insects have high feed conversion efficiency that can reach 50% in contrast with 12.55 for cows. Harmful insects that damage crops can be controlled through entomophagy i.e. harvesting them for human consumption and as animal feed. The question remains to be answered is whether people will accept consumption of insects or not. However, feeding insects to fish and birds may be accepted to some degree, as naturally fish and birds feed on various species of insects. This chapter summarizes the reasons favoring the consumption of insects, their nutritional composition, farming and mass rearing, harvesting from the wild and legislative measures of commercialization and processing.

## 2 The Reasons Favoring the Consumption of Insects as Compared with Other Meat Sources

There are many reasons as, listed below that encourage the farming of edible insects as human food and animal feed (Paoletti 2005; van Huis 2013; St-Hilaires et al. 2007).

(a) Edible insects represent an important alternative protein source.

(b) Farming of insects emit low emission of greenhouse gases and ammonia

The reduction in the greenhouse gases, in turn, reduce the impact on climate change; improve the livelihoods of communities, and affects positively on the environment.

(c) High feed conversation ratio

It has been reported that the house crickets *Acheta domesticus* are very efficient in converting feed into body mass as compared with livestock. This is attributed to the fact that they can maintain their body temperature with less metabolic energy (Paoletti 2005; van Huis 2013).

(d) The risk of zoonoses is very low in insects as compared with conventional livestock, because insects are taxonomically different from humans.

(e) Production of insects require less water than meat production and some of the edible insects such as the lesser mealworm *Alphitobius diaperinus* can tolerate drought.

(f) *Hermetia illucens*, commonly known as the black soldier fly can be used in conversion of organic waste into animal and fish feed that contain 42% protein and 35% fat (Sheppard et al. 1994). The addition of fish offal in the diet of the black soldier fly increased fat content of the larvae including omega-3 fatty acids (St-Hilaires et al. 2007).

(g) Insects have a high reproductive capacity and can complete many generations in relatively short time and they are easy to rear and require limited farming space. Production of insects require less capital and is thus, accessible to poor people with low income. The share of edible insects in food market is about $ 1.2 billion (Tajudeen 2020) indicating its important role in global food security. The aforementioned advantages of farming edible insects collectively demonstrate clearly their potential contribution to food security at local, national, and global levels. Production of edible insects meets the main criteria of food security such as availability, accessibility, safety, and fulfilment of dietary needs for both humans and animals.

## 3 Farming of Edible Insects

Farmed or domesticated insects are called mini-livestock or micro-livestock and can be used to convert agricultural waste into high-quality proteins (Paoletti 2005; Hoddle 2015). In this respect, agricultural waste could be transformed to useful products through insect biodegradation. For example, the red palm weevil, *Rhynchophorus ferrugineus* can be reared on refused on smash of palms or sugarcane or culled pineapple. An individual larva reared on these substrates can reach an average weight of 7 g. Artificial diet and date palm bolts could also be used to produce high-quality larvae of red palm weevil; however, the cost of production should be considered (Aldawood and Rasool 2011; El-Shafie et al. 2013) (Fig. 1).

Any developed rearing system for mass production of edible insects must be cost-effective, produce stable, high quality, and safe insects. Edible insects should be reared on plant-based diet and raised in clean hygienic conditions. The price of 420 g of canned sago worms (red palm weevil larvae) may sell for $12.80. This seemly high price may encourage farmers to raise this insect in commercial scales. The mealybug *Dactylopius coccus* produces carmine dye used as food additive in human diet, cosmetic purposes, and pharmaceutical products is a good example of domesticated insects. This insect, is collected from the wild prickly pear plants or plants in fences around the houses in Peru, while in Mexico, it is harvested form cultivated cactus plants (Aldama-Aguilera et al. 2005). Agricultural insect pests provide an essential source of proteins and can be collected from the forest and agricultural field (Piña-Dominguez et al. 2022). In organic fields, where insect pest are managed through environmentally friendly means (El-Shafie 2019); the harvested insects have the advantage of being free from insecticide residues.

**Fig. 1** Larvae of red palm weevil *Rhynchophorus ferrugineus* reared on artificial (meridic) diet under laboratory conditions. *Photo* Hamadttu El-Shafie

Palm weevil larvae are collected and consumed throughout the tropics. In many cases, weevil larvae are produced on naturally growing native palms and the influence of unwise insect collection can have a serious effect on the environment. This topic deserves detailed study as negative effects might accompany intensification (Choo 2008). Larvae of the African palm weevil, *Rhynchophorus phoenicis* are harvested, commercialized, and consumed as a delicious plate in some parts of West and Central Africa (Muafor et al. 2015; Okia et al. 2017; Debrah et al. 2019). Harvesting and commercializing larvae is a profitable business and represent a good source of income for rural peoples in Cameroon, Ghana, and Nigeria (Meutchieye and Nyassi 2016; Muafor et al. 2015; Commander et al. 2019). Local farmers rear the larvae in the cut stems of raffia palms of the genus *Raphia* with wounds along the stem to attract female weevils for oviposition. Such practice has led to widespread destruction of grown palms. Thus, sustainable methods of harvesting the African palm weevil should be investigated in order to avoid the overexploitation and devastation of palms (Muafor et al. 2015). In addition to Raphia palm, the African oil palm, *Elaeis guineensis* is also used as an alternative rearing source (Panduro-Pisco et al. 2021) and artificial rearing media are also being developed (Ebenebe and Okpoko 2016; Quaye et al. 2018).

In Thailand and Indonesia, *Rhynchophorus ferrugineus* is reared in closed plastic containers where coconut palm fronds are ground up using a mechanical grinder and the resulting sawdust is soaked in water (Hoddle 2015). Excess water is squeezed then to make a palm smash which is tightly packed in the containers. Adult weevils are then introduced into these containers for egg laying. Slaps of palm wood and barks are placed on the top of these containers as covers. The larvae then develop inside these containers and are harvested when they reach the pre-pupal stage in which they gain the maximum body weight (Hoddle 2015). The water that drip from the rearing containers as well as the solid waste after harvesting larvae can be sold as fertilizers and for soil amendment (Hoddle 2015) (Fig. 2).

## 4 Nutritional Composition of Edible Insects

In Papau New Guinea, the palm weevil, *Rhynchophorus bilineatus* can supplement the amino acids lysine and leucine, which are lacking in the stable diet of local people. Protein contents of some insects ranges between 35 and 60% of their dry weight, which is higher as compared with sources of plant origin (Schlüter et al. 2017). Fat, on the other hand, is the second highest nutrient content of edible insects, which may reach 50% (Seni 2017). The nutrient content of edible insect particularly proteins and fats vary greatly with the species, rearing diet, developmental stage (larva, pupa, and adult), insect sex (male or female), and the process of preparation such as boiling, drying or frying (Chinarak et al. 2020; Ojha et al. 2021) (Table 1). For example, rearing *R. ferrugineus* on sago stem diet in Thailand resulted in larval lipid content of 60% composed mainly of palmitic and oleic acids (Chinarak et al. 2020). The protein contents of the order Orthoptera is the highest among the

**Fig. 2** Larvae of red palm weevil harvested from palm trunks filled with palm mash in Thailand. *Photo* Courtesy of Mark Hoddle

different orders, while Coleoptera is well known for its high fat contents. On the other hand, Hemiptera and lepidoptera contain more fiber and energy level, respectively (Rumpold and Schlüter 2013). Beside important vitamins such as A, C, B1 and B2, insects are rich in minerals including potassium, copper, zinc and iron (Al-Fattah et al. 2009). The highest vitamin A content was recorded in adult *Zonocerus variegates* (Orthoptera), vitamin E in *Galleria mellonella* (Lepidoptera), and vitamin B1 in larvae of *Rhynchophorus phoenicis* (Coleoptera) (Rumpold and Schlüter 2013). The insects' proteins contain unsaturated fatty acids and their digestibility rate may reach 98% (Bukkens 1997; Finke 2002). Additionally, insects provide materials that are used as natural food additive (Srivastava et al., 2013). Nutritionally, 100 g of the African palm weevil, *Rhynchophorus phoenicis* larvae can provide 182 kcal of energy, 6.1% protein, 3.1% fat and 9% carbohydrates, in addition to 4.3 mg and 461 mg of iron and calcium, respectively (Mercer 1997). For more details on the nutritional composition of edible insects, please refer to Devi et al. (2023). *Rhynchophorus phoenicis*, *Macrotermes bellicosus*, *Oryctes rhinoceros* and *Imbrasia belina* contain all essential amino acids particularly lysine, threonine and methionine (Ekpo 2011). Chitin, chitosan, and chitooligosaccharides found in insects were reported to have immunity-enhancing effect, checking pathogenic microorganisms, and enhancing the growth of beneficial bacteria (Lee et al. 2008; Liu et al. 2010).

**Table 1** Protein and fat contents (%) of the most common edible insects worldwide based on dry weight

| Insect species | Stage | Protein | Fat | References |
|---|---|---|---|---|
| African palm weevil *Rhynchophorus phoenicis* | Larvae | 35.63 | 19.50 | Halloran et al. (2014) |
| Honey bee *Apis mellifera* | Larvae | 42.00 | 19.00 | Chen et al. (1998), Al-Fattah et al. (2009), Halloran et al. (2014) |
| House cricket *Acheta domesticus* | Adults | 60–70 | 10–23 | Udomsil et al. (2019) |
| Lesser mealworm *Alphitobius diaperinus* | Larvae | 60 | 29 | Adámková et al. (2016) |
| Migratory locust *Locusta migratoria* | Adults | 50.42 | 19.62 | Mohamed (2015) |
| Mopane caterpillar *Imbrasia belina* | Larvae | 54.26 | 23.38 | Rumpold and Schlüter (2013) |
| Silkworm *Bombyx mori* | Larvae | 58.00 | 35.00 | Halloran et al. (2014), Hăbeanu et al. (2023) |
| Yellow mealworm* *Tenebrio molitor* | Larvae | 44.93 | 37.85 | Toviho and Basony (2022) |

*Authorized by the European commission as novel food for the EU

## 5 Risk Assessment and Legislative Measures

The European commission has recently approved cricket flour to be used in selected food under "Novel food" regulation. The commission has already approved dried *Tenebrio molitor* larva, frozen, dried and powdered form of *Tenebrio molitor* and frozen, dried and powdered forms of *Locusta migratoria* (Fernandez-Cassi et al. 2018). There are about 8 files which are being assessed by the European Food safety Authority (EFSA). The partially defatted powder obtained from the whole house cricket (*Acheta domesticus*) is to be used in multigrain bread, rolls, crackers, breadsticks, cereal bars, biscuits, sauces, pizza, and soup. Novel food is defined as "food that had not been consumed to a significant degree by humans in the EU before 15 may 1997" (Fernandez-Cassi et al. 2018). EFSA must conduct a scientific risk assessment to make sure that it is safe for human consumption. The EU approved that frozen, dried and powder form of *Tenebrio molitor* larva, *Locusta migratoria* and *Acheta domesticus* be used in biscuits, legume-based dishes, past-based products and the maximum level is 10 g/100 g. Food containing insect ingredients should be properly labelled with clear warning for consumers having allergies to crustaceans and other arthropods (Fernandez-Cassi et al. 2018). According to the European regulation and guideline, insects should be treated as livestock and therefore, special good farming practices (GFP) as in the case of livestock should be adopted for them (Fernandez-Cassi et al. 2018). Few countries around the globe have legislations on production, processing, wild harvesting, safety measures, and commercialization of edible insects (Li et al. 2021). Care should have to be taken in the case of harvesting pests of crops as human food. For example, in many Gulf countries desert locust *Schistocerca gregaria* is collected as food during plagues to avoid insecticide residues in sprayed insects. In 1988/1989, insecticide residues were detected in locusts collected from the swarms that invaded the country and despite of this, the local population in Kuwait consumed them (Saeed et al. 1993). Harvesting of insects from wild habitats should be regulated at local, national, and international levels to ensure sustainability (Piña-Dominguez et al. 2022). Regulation (EU) 2283/2015 entered into force in 2018 approving edible insects as novel food in Europe (Fernandez-Cassi et al. 2018). The risk profile of the house cricket *A. domesticus* comprises of closed rearing system and good farming practices to ensure that all processes across the production chain are safe and according to the standards According to this risk profile, hazards such as presence of harmful bacteria, fungi, viruses, and heavy metals should be low (Fernandez-Cassi et al. 2018). Thailand has released the first Good Agricultural Practices (GAPs) for cricket rearing which is considered an important source of income for farmers after rice cultivation. The practices cover four species of cricket, *Gryllus bimaculatus* De Geer, *Teleogryllus testaceus* (Walker), *T. occipitalis* (Serville) and *Acheta domesticus* (L.) (ACFS 2017). Edible insects are now recognized at the international level by Codex Alimentarius, the regional level by the European Union, and the national level by Switzerland and Belgium (Halloran et al. 2014).

## 6 Entomophagy and Acceptability of Edible Insects as Human Food

The eating of insects by humans (entomophagy) is commonly regarded as a primitive practice in developed countries and is liked with communities in poor countries (van Huis 2013). However, this believe start to change with the growing awareness of the western communities about the benefits of edible insects consumption. The close relative of insects, which include lobsters, craps and prawns (crustaceans) collectively known as aquatic arthropods are accepted and readily consumed by humans which may encourage the consumption of insects. Presenting edible insects in different forms rather than in their natural body shapes might positively influence human acceptability. For example, removing insect appendages, particularly the legs and wings may render them more acceptable for consumption by humans (Nakagaki and deFoliart 1991). Flours with dried powdered ingredients of edible insects seem to be the most accepted format for human consumption (Ros-Baró et al. 2022). Food safety, feeling of disgust, and lack of familiarity may be the main reasons behind the human reluctance to eat insects. Thus, adding ingredients form insects to other familiar diets may increase their acceptability by humans (Halloran et al. 2014; Ros-Baró et al. 2022). Factors that might affect human acceptability to eat insects include, but not limited to, neophobia, social norms, familiarity, and awareness of the merits of insects consumption (Ros-Baró et al. 2022). Traditions and social norms play an important

**Fig. 3** Stir-fried red palm weevil larvae with a traditional sauce of Thai herbs and spices. *Photo* Courtesy of Mark Hoddle

role in acceptance of edible insects as food by humans (Fernando et al. 2023). An ad-hoc questionnaire comprising 1034 participants was carried out in Catalonia (Spain) to study the main reasons that affect consumption of insects as a de novo source of protein. In Western countries, consumer acceptability is determined largely by prices, benefits to the environment, and appearance, in the market, of delicious and appealing products containing insect ingredients (Halloran et al. 2014). In Egypt, red palm weevil larvae are readily consumed by humans and are prepared in different forms such as boiling, frying, and baking (Abdel-Moniem et al. 2017). In Thailand, stir-fried red palm weevil larvae with a traditional sauce of Thai herbs and spices is served with steamed rice as a popular meal and roadside signs advertising for red palm weevil sale are common (Hoddle 2015) (Figs. 3 and 4).

## 7 Entomophagy in Saudi Arabia

There are about ten species of locusts eaten by human around the world (Egonyu et al. 2021). Arab used to consume locusts and their eggs as part of their tradition before Islam. There are many sayings (Hadiths) by Prophet Muhammed PBUH support the consumption of locusts as halal food (Tajudeen 2020). In Saudi Arabia, locust particularly the desert locust, *Schistocerca gregaria* is seasonally collected from swarms and consumed as boiled or toasted with addition of salt (Emirates 2013). There are special markets for locusts in Buraidah and Al-Ahsa and the price

**Fig. 4** The red palm weevil expert Prof. Dr. Mark Hoddle eating red palm weevil larvae in Thailand. *Photo* Courtesy of Mark Hoddle

of a bagful of locust weighing 2 kg may reach $133, depending on the size and quality of the insects. The people who consume locusts feel that this a part of their traditions inherited from their grandparents (Saudi Gazette 2023; Arab News 2023). Young generations are reluctant to consume locusts and conceiving the issue with disgust, while the older generations are showing more interest in eating locusts. Some Saudi people are eager to consume locust, despite the banning by the authorities on the ground that insecticides might contaminate these locusts during swarms control campaigns. However, encouraging farming of locusts in controlled systems may solve this problem. Additionally, research is going on in Saudi Arabia on the possibility of replacing conventional fishmeal by locust meal in the fish farming in order to reduce feed costs (Yousif et al. 2022). Another insect pest that might be exploited as a source of protein as animal feed is the red palm weevil, *R. ferrugineus*. This destructive pest is responsible for destruction and removal of thousands of date palm annually. Exploitation of red palm weevil larvae as animal feed may be considered one way of pest management to reduce weevil populations and the resulting economic loss.

## 8 Conclusion and Prospects

The increasing demand for more proteins sources to meet the needs of the world growing population necessitates the search for new sources of food. Insects are rich in proteins, fats, vitamins, and minerals therefore they can represent a potential protein source in the future that can contribute much in global food security. However, the challenges are so big to produce more food and feed from edible insects in environmentally sustainable manner. To achieve a sustainable insect production system with high quality, more research is needed concerning mass rearing, preservation, processing and marketing. Moreover, adoption of strict legislations and standards at local, national, and international levels is required. Raising people awareness about the benefit of insects' consumption and improvement in consumer acceptance may favor the development of edible insects industry in the future.

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# Chapter 18
# Food Processing in Saudi Arabia

**Salah Aleid**

**Abstract** Saudi Arabia has formulated a comprehensive plan to attain food security by relying on its own resources. The core objective is to enhance self-sufficiency by increasing the domestic production and processing of food, aiming to localize 85% of the food processing by the year 2030. The major food industry sectors in Saudi Arabia are represented in grain storage, wheat milling and baking industry, dairy industry, dates industry, red meat, poultry, and seafood Industry, and cold chain infrastructure. The available silos storage capacities of wheats is 3.45 million metric ton. The bakery sector is experiencing annual growth of 5–7% due to the bread segment, which constitutes 50% of the market. The dairy industry in Saudi Arabia is more capital intensive with a dairy market valued at USD 5726.4 million in 2020. Saudi dates accounts for 11.5% of global production making it a suitable market for exports. Saudi Arabia recently ranked first (worldwide) in date exports in 2021 in terms of value reaching 1.2 billion Saudi riyals. In 2021, Saudi Arabia has reached a level of 30% self-sufficiency in the red meat sector and 65% self-sufficiency in domestic poultry production. The country intends to boost its food security by increasing self-sufficiency even more, in alignment with the National Industrial Development and Logistics Program of Vision 2030. There is a high demand for cold chain facilities during Hajj and Ramadan as storage facilities usually witness maximum capacity utilization during this period. The food exporters to Saudi Arabia make an effort to adhere to the regulations of importing food set by SFDA. They ensure proper labeling and preregistration of their products to minimize the chances of being rejected at the ports of entry in Saudi Arabia. The SFDA has established a halal food center which offers a range of services, including the issuance of certificates for halal food products. The Saudi Arabian food sector is receiving significant investments as the country aims to enhance its food security. By 2021, the Kingdom has received approximately US$ 59 billion worth of investments in its food industry.

**Keywords** Cold-chain · Dairy · Dates · Food security · Meat · Processing · Regulations · Seafood · Wheat

S. Aleid (✉)
Department of Food and Nutritional Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: seid@kfu.edu.sa

 
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## 1 Introduction

Despite currently having a relatively high food security index score, Saudi Arabia is highly susceptible to food insecurity in the future. The country's food security situation is below the global average, especially concerning water resources. As the largest food importer in the Middle East, Saudi Arabia relies on foreign sources for approximately 80% of its food supply. However, it is worth noting that the country now possesses 1121 food factories (Sialparis 2021). Saudi Arabia imports 70% of its food needs, spending approximately SR87 billion every year. The food industry in Saudi Arabia is currently experiencing investment opportunities, both in the present and in the future. According to Sajid and his colleagues (2018), the Saudi Arabian Agriculture Development Fund is a Saudi bank that finances the agricultural and food sector. It was founded as an effective and specialized financial institution in all areas of agricultural activity in Saudi Arabia. The primary goal of establishing this institution is to contribute to improving the development of the agricultural sector and increasing its productivity by utilizing modern scientific methods and technologies. Importantly, the bank assists farmers by giving loans to support agricultural sector activities at no interest rates. In 2009, a fund of 20 billion riyals was allocated as an asset. The fund aims to support agricultural development and sustainability while also considering water conservation, rationalization of agricultural uses, and environmental preservation (Sajid et al. 2018).

The food industry in Saudi Arabia is considered highly appealing in the region due to its strong sales and growth prospects (Fodex Saudi 2017). The government's initiatives to overcome obstacles to foreign investment are expected to attract significant investment in the food processing sector, mainly in key segments that contribute to the growth of local processed food production. Despite pressure on the labor market, the food sector will benefit from a large population of approximately 34.1 million, with an average household size of 6.4 individuals (Fodex Saudi 2017). This will increase the demand for processed food and improve the spending environment for consumers (Aljazira Capital 2017). Food industry in Saudi Arabia consists of several sectors represented in dairy Industry, juice and beverage bottling, fruit and vegetable packing, fish Industry, grain and wheat milling, baking industry, oil and fat industry, animal and poultry slaughtering and processing, chocolate, candy, and sweet products.

## 2 Wheat Milling and Baking Industry

Saudi Grains Organization SAGO (Previously named Grain Silos and Flour Mills Organization) approved taking the necessary actions to establish four joint-stock companies for flour mills and to manage the silos activity, running, development and improvement. In addition to the tasks of organizing, controlling and supervising the activity of flour-producing mills.

SAGO is a Saudi government agency that has been given exclusive authority to carry out the approved policies, plans, and programs aimed at improving the activity of silos and flour mills. It is also responsible for adopting the appropriate procedures. The agency purchases wheat directly from the global market by using public tenders. Prior to the privatization of the milling industry, the organization processed the wheat and sold the resulting flour within the country at a significantly reduced price to cater to the demands of bakeries, industrial consumers, and supermarkets. SAGO operates nine mills situated in key regions of Saudi Arabia, with a collective daily maximum capacity of milling 11,430 metric tons (MT) of wheat (Saudi Grains Organization 2023).

Saudi Arabia succeeded to privatize the nine flour mills to the private sector in a step to attract and encourage investments in this sector and strengthen competition. SAGO has finished the privatization through an elaborate program that passes through different stages: (a) worked for separating the processes of milling from wheat storage silos; and (b) established flour groups of four milling companies.

For the time being, SAGO main duties are to (a) buy and sell wheat, and create a reserve stock of wheat that meets the need of the kingdom and maintain its balance periodically; (b) organize, control, and supervise the silos and flour mills activity; (c) control the wheat quality and the production of the flour milling companies. Provide the required quantities of wheat to operate the flour milling companies according to the pricing policy suggested by the organization in accordance with the government's market support policies. Moreover, SAGO controls the competition regulations in the field of services provided for soils and flour mills activity, protects consumers in matters related to the products of silos and flour mills and suggest pricing policy for the products of flour mills activity (Saudi Grains Organization 2020).

## *2.1 Wheat Storage in Saudi Arabia*

In recent years, several new projects for wheat silos have been started. Although storage silos may not be more cost-effective to construct and oversee, they are still significantly less expensive compared to cultivating cereal in a challenging climate. The annual cost of storing wheat in Saudi Arabia is about $70 million, considerably lower than the estimated cost of production subsidies, which reached approximately $5 billion per year between 1984 and 2001 (Mousa 2014; Sajid et al. 2018). The available storage capacity of the SAGO is 2.7 million MT of wheat in 14 locations. Moreover, the available storage capacities of the silos of the four privatized milling companies is 0.75 million MT resulting in a sum of 3.45 million MT (of wheat, which can meet the consumption for one year (Saudi Grains Organization 2020). The total actual quantity received of imported wheat during the year 2020 was about 3.27 million MT as could be seen in (Fig. 1).

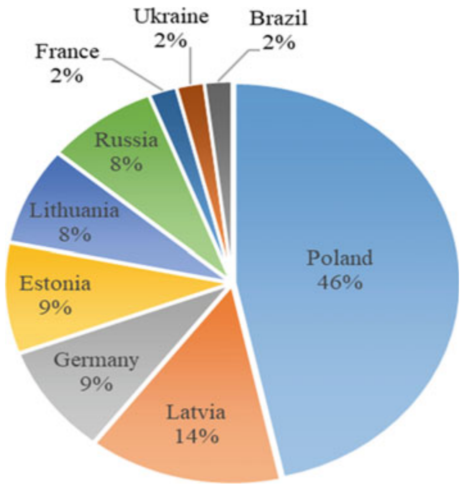


**Fig. 1** Imported wheats base on countries of origin 2020. *Source* Saudi Grains Organization (2020)

## 2.2 *Wheat Flour Milling*

The total amount of wheat used in the production of flour and wheat derivatives by the four milling companies during the year 2020 was about 3.4 million MT. From this amount, the total produced flour amounted to about 2.65 million MT. The total production of other wheat derivatives (wheat germ, human bran, pearled wheat) during the year 2020 amounted to about 3700 tons. The total production of the four milling companies of fodder reached 0.56 million MT (Saudi Grains Organization 2020).

Many varieties of flour are produced as follows: (a) powder flour (75–80% Extraction); (b) fine flour (70–74% Extraction); (c) ordinary flour (85% Extraction) and (d) whole wheat flour (95% Extraction). The extraction rate is a measurement of the proportion of grain that is converted into flour while it goes through the milling process. Flour with a higher extraction rate contains a greater percentage of the bran, germ, and outer layers of the endosperm. Whole-wheat flour has a 100% extraction rate, while white flour typically has an extraction rate of approximately 72% (The Sourdough School 2023). In addition, flour is marketed to the customers as follows: (a) a commercial bulk in 45 kg bags; and (b) for domestic customers in small bags of 10, 5, 2 and 1 kg.

## 2.3 *Bread and Pastries Market in Saudi Arabia*

The bakery product market in Saudi Arabia is anticipated to experience substantial growth due to the increasing awareness of health and wellness, as well as the shift towards whole-wheat bakery items. The rising demand for whole grain and gluten-free options, coupled with changes in consumer lifestyles and the convenience, accessibility, and nutritional value of bakery products, will contribute to the robust growth of the bakery product market in the coming years. The size of Saudi Arabia's bakery product market is expected to see significant growth between 2020 and 2026. The Saudi Arabian government is ensuring a continuous food supply and taking measures to overcome the gap between demand and supply, which promotes the sales of bakery products in the country (6Wresearch 2020).

The bakery market in Saudi Arabia is maintaining its momentum. The sector is experiencing a 5% to 7% growth year on year, mainly due to an increase in population, accessibility, and wealth. The trend of preferring fresher bread and pastry products is becoming stronger among consumers, leading to a shift from supermarket bakeries to specialized bakers. The bread segment accounts for 50% of the market, followed by cakes and pastries. The demand for gluten-free products is also gaining traction, along with an increase in the use of organic ingredients and purchases of wheat and brown bread. Companies like L'usine have introduced a popular retail pack of croissants with fillings such as chocolate and strawberry (Renkoski 2019).

Snack bars are commonly used as a replacement for meals in the Middle East due to their high protein content and good nutritional value. In Saudi Arabia, the market for snack bars is expected to reach $60 million by 2024, with a compound annual growth rate of 12% from 2019 to 2024. There is a high demand for snack bars that are rich in fiber, low in sugar, gluten-free, and contain a mixture of grains. The growing trend of snacking presents opportunities for market development and innovation. Additionally, consumers are attracted to healthy baked goods that are reasonably priced (Renkoski 2019).

## *2.4 Bread Baking in Saudi Arabia*

There is a movement towards healthier products, particularly in the bread category. One example is the widely consumed type of bread in Saudi Arabia, which is Arabic bread. Arabic bread originated in the Middle East and is a round flat bread with two layers. These breads share similar characteristics in terms of quality. The two-layered structure of flatbreads is formed through the use of steam while they are baked in a hot oven, reaching temperatures of 370–500 °C. Within the last ten years, there has been a shift toward automated manufacture of these types of breads (Quail et al. 1991). Arabic bread dough has a high water absorption level (70–75%). Water absorption has a significant impact on the bread physical characteristics and flavor (Qarooni 1990). Because of higher absorption, the dough separates into two layers as steam expands forcing the product to form a pocket if the dough has enough second proof. Arabic bread processing involves mixing, primary fermentation, dividing (scaling) and rounding, intermediate proofing, two-dimensional sheeting to desired thickness, final proofing, baking, cooling, and packaging (Qarooni 1990) Arabic breads can be white or brown, depending on the flour extraction rate. White bread is made from 72% extraction flour; brown Arabic bread is made from 90 to 95% extraction flour

(Faridi and Rubenthaler 1984). The ideal Arabic bread color was described as a cream to pale brown with no patches, and the internal crumb should have small cells (1–2 mm in diameter) evenly distributed. The poor texture is an indicover-fermentation. Arabic breads may be soft, chewy, or sticky, tender tough or leathery, depending on flour properties. White flour made from hard wheat with a moderate strength and protein content of 10–12% resulted in the production of high-quality Arabic bread.

Another popular type is a single layered Tanoor bread. The “Tanoor is an oven usually made of clay, usually used to bake leavened or unleavened flat breads”. The temperature inside the Tanoor is kept near 480 °C. The dough has no final proofing however docked for decoration purposes and prevent pocket formation in the oven. Crust color is a reddish brown. A high quality Tanoor bread has uniform thickness with even distribution of small blisters on the top crust (Qarooni et al. 1993). Due to limited shelf-life and fast staling characteristics of flat breads, emulsifiers and enzymes were added to the ingredients to strengthen and condition the dough and extend shelf-life, which result in the reduction of bread waste by consumers.

The dough is prepared using the straight dough method, which involves a fat-free formula based on the baker’s ratio (flour 100, water 72, salt 1.5 and instant active dry yeast 0.5). The bread making procedure is outlined in Fig. 2.

## 3 Dairy Industry in Saudi Arabia

Saudi Arabia achieved high levels in self-sufficiency dairy industry by raising production at high rates. The juice is usually manufactured in parallel with milk products such as fresh milk, long-life milk, flavored milk, fermented cultured milk, yogurt and flavored yogurt.

### *3.1 Dairy Market in Saudi Arabia*

The dairy market in Saudi Arabia is predicted to experience significant growth by 2026. This is due to the thriving dairy industry and the growing demand for milk and other dairy products. As a result, many international companies are entering the market since the country heavily relies on imports to meet its dairy needs (TechSci Research 2021; Research and Market 2021). The dairy market of Saudi Arabia was worth USD 5726.4 million in 2020. It is projected to exhibit a compound annual growth rate of 5.6% during the forecast period and is anticipated to reach USD 7940.7 million by the end of 2026. According to a report by Research and Markets (2021), the drinking milk segment holds the largest market share and is projected to continue dominating the market until 2026. In Saudi Arabia, the volume of drinking milk consumption stands at 64.2 kg, while the per capita consumption of cheese has almost reached the same level as in the United States, with 13.2 kg. The difference between demand and supply is typically reduced by the production of UHT

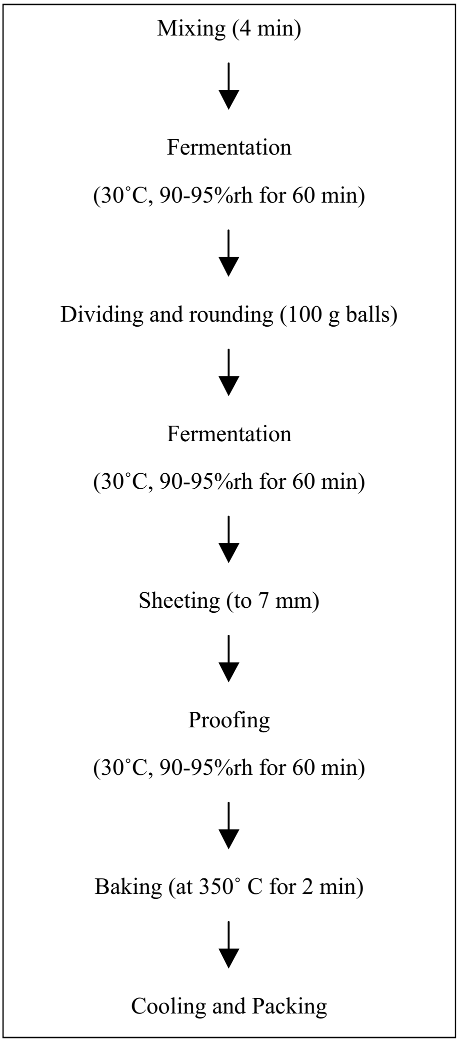


**Fig. 2** Experimental Arabic bread procedure

milk, which has a long shelf life. In Saudi Arabia's dairy market, there is a growing popularity for value-added dairy products such as "ghee, butter, cheese, ice cream, probiotic drinks, and others".

The demand for these products is driven by increasing income, population growth, and changing eating habits in the country. Furthermore, value-added enhancements in dairy products contribute to an increase in demand for them. Some of these enhancements include the creation of low-fat cheese, sugar-free ice cream, and the introduction of various flavors to yogurt. Additionally, the consumption of milk holds the majority portion of the market and is projected to continue dominating until 2026. This market is highly competitive, with companies striving to stand out by promoting innovative new products to expand their market share (TechSci Research 2021). Over the past few years, a variety of competitive strategies have been employed by dairy food companies in Saudi Arabia (Sadi and Henderson 2007).

## 3.2 Dairy Consumption in Saudi Arabia

Dairy products are acknowledged as an essential part of the Saudi Arabian diet, and there is evidence to support their popularity among the growing population (Sadi and Henderson 2007). The Per capita consumption of all dairy products in Saudi Arabia was 136 kg ME/capita, (ME = Milk equivalents, method "fat and protein" only) in 2013, while the per capita consumption in 2017 of only liquid milk was 64.2 l/year (European Association of Dairy Trade 2017). Volume of drinking milk in Saudi Arabia is 64.2 kg and the overall cheese per capita consumption is already almost at the same level as in the USA (13.2 kg) which is extremely high for a non-western country. Butter consumption per capita has already a fairly high level in Saudi Arabia (2.2 kg), and most of the butterfat is consumed in retails. The per capita consumption of yogurt is 7.5 kg (European Association of Dairy Trade 2017).

According to the research conducted by Sadi and Henderson (2007), the dairy food industry in Saudi Arabia is relatively advanced. The progress made in the fields of science and technology, as well as the processes of modernization and globalization, have resulted in significant changes in the behavior of Saudi consumers. These changes can be seen in their distinct preferences and purchasing patterns, as well as the way they evaluate different marketing options available to them. As a result, there is a need to enhance current products and develop new ones to meet these evolving needs. The market is also maturing, leading to increased competition both domestically and internationally. Additionally, there has been a shift in the government's approach, with a reduction in subsidies and a stated reluctance to interfere with market dynamics (Sadi and Henderson 2007).

## 3.3 Dairy Farming in Saudi Arabia

In the early 1970s, Saudi Arabia launched executive programs to support the development of dairy farming. The main goal was to achieve self-sufficiency in milk production. A significant amount of funding was allocated to import high-quality cattle that adhered to industry standards, as well as to introduce advanced technology in processing, packaging, and distribution (Alqaisi et al. 2010; Algaisi 2013). Saudi milk production has increased from 1.34 million tons in 2007 reaching 2.5 million tons in 2020 from a total of 364,389 milking caws, with an annual growth rate of 5% (General Authority for Statistics 2018) as could be seen from (Table 1).

There are only a few dairy farms in Saudi Arabia, even though each farm has a large number of cows. Recent statistics from Saudi Arabia indicate that the big

**Table1** Fresh whole milk production (metric ton)

| | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|
| Milk, whole fresh cow | 2,138,000 | 2,159,000 | 2,074,562 | 2,393,771 | 2,593,771 |
| Milk, whole fresh camel | 131,448 | 132,585 | 133,082 | 134,272 | 135,926 |
| Milk, whole fresh goat | 67,962 | 68,448 | 67,698 | 69,025 | 96,212 |
| Milk, whole fresh sheep | 83,875 | 84,453 | 84,892 | 85,070 | 85,270 |

*Source* FAO (2023), https://www.fao.org/faostat/en/#data

dairy farms use modern technology that requires a significant amount of capital for production and processing. Many of these farms are located in the Al-Kharj area, which is near the capital city of Riyadh. This region has a less humid climate, making it more suitable for raising cattle. The dairy industry in Saudi Arabia faces a major risk from increasing feed prices because the country relies on imported feed for the animals. Moreover, the scarcity of water resources, particularly in Saudi Arabia, will limit the production of animal fodder (Alqaisi et al. 2010; Algaisi 2013).

### *3.4 Dairy Processing in Saudi Arabia*

The full range of pasteurized fresh dairy products is available in Saudi Arabia. The four major producers of liquid milk in the country are "Almarai, Al-Safi, NADEC, and NADA". These companies are responsible for nearly all the sales of fresh, pasteurized milk, laban, and yogurt (AL-Otaibi and Robenson 2002; Algaisi 2013). They produce their own fresh milk and have their own dairy farms. On the other hand, other dairy producers import large amounts of powdered milk. Additionally, other factories gather raw milk from various farms throughout the country. Riyadh province has about 16 dairy factories, the eastern province has 14, and the western region has eight. The remaining factories are scattered across different parts of the country. Some of the products, such as probiotic culture laban and milk, have a positive impact on overall health and aid in maintaining a healthy digestive system. For instance, the Almarai dairy company offers a wide range of nutritious food and beverages in Saudi Arabia. These include flavored milks and lactose-free milk, yogurts and desserts, cheese spreads and slices, as well as butter, ghee, cream, mozzarella, and fruit juices (Ajay and Hagahmoodi 2017).

The difference between demand and supply can be reduced by producing UHT milk, which has a long shelf life. Almarai is one of the largest dairy farms in the world, with a total of 135 thousand dairy cattle. The whole herd produces 2.5 million liters of 2013milk per day, averaging about 40 L/cow/day, which is roughly two folds of the European average (Cable News Network 2013; Agriland 2016). The milking plants in the Arabian Gulf region use a standard known as the "Californian model" to operate dairies in some of the driest regions in the world. The Californian model involves not relying on growing all the grass and feed crops on-site, but instead

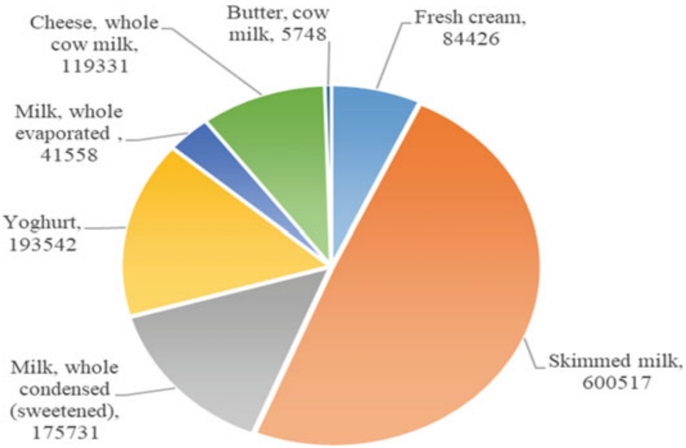


**Fig. 3** Amounts of processed milk products in 2019 (metric ton). *Source* FAO (2023), https://www.fao.org/faostat/en/#data

importing feed and most inputs for housing a thousand dairy cattle on just 40 acres of land. As long as water and feed can be obtained, this type of dairy operation is sustainable (Cable News Network 2013). The amounts of processed milk products in 2019 (metric ton) are represented in Fig. 3.

Taking into account production factors, the quantity of milk utilized for the production of yogurt products greatly surpasses the amount of milk redirected towards the creation of pasteurized or sterilized milk. In Saudi Arabia, the majority of processed pasteurized milk is derived from fresh milk, with the exception of a few facilities that produce sterilized UHT milk utilizing recombined skim powder and milk fat (Salji et al. 1983). The manufacturing practices for processed fluid milk involve the use of modern technology and adequately equipped facilities. Fresh milk collected from the milking parlor is either pumped or transported to the processing plant. The raw milk is then cooled using either bulk coolers or, more efficiently, plate coolers. Typically, the raw milk is processed within 24 h of milking. When using powdered milk, a process called recombination occurs. This process involves adding melted butter to a liquid mixture made up of skim powder, stabilizer, and water. As a result, all the components blend together before undergoing heat treatment. Heat treatment of milk involves the utilization of high-temperature-short-time (HTST) pasteurization and ultra-high temperature (UHT) treatment. The HTST method is predominantly employed, utilizing a wide range of temperature–time application in facilities. The temperature ranges from 72 to 94 °C, and the holding time ranges from 3 to 30 s. After being homogenized and pasteurized, the product is packaged in either Pure-Pack cartons or form-and-fill plastic containers. It is then stored refrigerated at temperatures between 4 and 8 °C (Joseph et al. 1984).

# 4 Dates Industry in Saudi Arabia

There has been significant support and development in the agricultural sector as a whole, and specifically in the date palm industry, in Saudi Arabia over the past few decades. Leading date producers in Saudi Arabia are increasing their investment in top-notch facilities and operations. There are numerous large farms in Saudi Arabia, and they are making significant investments in new or replacement trees that are not yet producing. This indicates further growth in production capacity. The number of palm trees is 33 million representing 27% of the total palm trees in the world (Al-Khayri and Johnson 2013).

## *4.1 Dates Exports and Local Market in Saudi Arabia*

There is a vast diversity of date palm cultivars in Saudi Arabia; the most notable are "Khalas, Sukkari, Ajawa, Anbara, Ruthana, Segae, Barhee and Ruzeiz". In the production and marketing of dates, the main focus should be on quality. To ensure that Saudi dates remain competitive, it is important to evaluate the attributes desired by consumers. The value attached to these dates can come from both the characteristics of the product and the conditions of its production. To measure these values, it is necessary to analyze consumer behavior in current markets or conduct interviews with consumers to understand their perceptions of price and product quality (Carlsson et al. 2005).

Saudi Arabia recently ranked first (worldwide) in date exports in 2021 in terms of value, according to what was announced by (TradeMab) website of the World Trade Center. The export value of dates during the same year amounted to 1.2 billion Saudi riyals, and the number of palm trees is 33 million palm trees, this represents more that quarter (27%) of the total palm trees in the worldwide. Saudi dates "Trade Mark" brand logo for factories is a sign that the products obtained are safe. It is based on standard specifications for Saudi dates, which are classified into three grades (excellent, first, and second choice) to fulfill the technical and standard requirements in food safety, which comply with the requirements of international markets. The brand advantages are;

(1) raising the market value of Saudi dates; (2) ensuring a high level of quality; (3) increasing marketing opportunities in the local and international markets, and (4) advancing nutritional value for the consumer (National Center for Palms Dates 2023).

## 4.2 Dates Consumption in Saudi Arabia

Consumers develop their opinion about the quality of dates primarily by taking into account specific factors such as the type of date, taste, texture, size, color, crust cohesion, freshness, absence of skin fractures, and being free from insects. Recently, consumers in the Saudi market have been expressing increasing concerns regarding the quality of dates.

As a result, date markets have started employing strategies to differentiate their products and attract consumers based on different date characteristics. This differentiation is achieved by highlighting unique attributes and conveying them through labeling (Aleid et al. 2014; Al-Kahtani et al. 2011). Recently, there have been changes in eating habits in Saudi Arabia. However, certain traditional practices, like consuming dates, are still common. Dates are a significant fruit in Saudi culture, and their consumption in the country is one of the highest in the world. People in Saudi Arabia consume approximately 100 g of dates per day, which can provide around 10% of their daily energy requirement and 4% of their non-starch polysaccharide requirement (Al-Mssallem 2018). According to the Food and Agriculture Organization, the average person in Saudi Arabia consumed 39.2 kg of dates in 2019, representing a 5.52% increase from 2018 (FAO 2023).

Date palm fruits are widely consumed at two different stages of ripening, termed in Arabic as Rutab and Tamer. The sugar in date fruits is high and reaches about 53% in Rutab and 73% in Tamer. Despite this high content of sugar, the average glycaemic index and glycaemic load values of more than 30 varieties of commonly consumed date fruits are 52 and 9, respectively. These Figures indicate that the total glycaemic impact of date fruits on blood glucose levels is low. This favorable postprandial effect (relating to the period after meal) of date fruits is particularly attributed to their content of fructose (28/100 g) and non-starch polysaccharides (10/100 g). In addition, date fruits are a good source of some macro- and micro-minerals such as potassium, magnesium, and selenium (Al-Mssallem et al. 2018).

## 4.3 Date Processing and Packaging

After the harvest, workers sort the dates by hand, removing any dates that are damaged or infested, as well as any foreign objects. The processing of dates includes removing the stem and, in certain instances, the seeds to enhance their market value and minimize transportation expenses (Barreveld 1993). The removal of date seeds can be achieved by crushing and sieving the fruits or, more advancedly, by mechanically pitting the fruit (Mahmoudi et al. 2008). The next step includes fumigating and sterilizing the fruit to avoid any harm caused by pests. The main techniques to prevent insect infestation are fumigation, heat treatment, cold storage, and irradiation. Among these, fumigation is the most frequently used technology. Heat treatment and cold storage are advantageous for dates due to different reasons, while irradiation is an effective but less commonly utilized method (Ashraf and Hamidi-Esfahani 2011). Fumigation is the initial process carried out after fruits are harvested to protect them from being infested. In the date industry, there are significant losses caused by insect damage. Infestations of dates by various moth species such as "almond moths, meal moths, fig moth (*Ephestia cautella*), Indian meal moth (*Plodia* interpunctella), beetles like sap beetles, sawtoothed grain beetles, flour beetles, as well as rats, mice, and ants, lead to contamination and a decrease in quantity" (Glasner et al. 2002).

In the next step, the dates are sorted based on their size, color, and moisture content. Afterward, the usual practice is to clean them with automatic machines that use water sprays to eliminate dust and any other foreign substances. This process is carried out with clean water. Date processors typically use wash-water sanitizers to decrease microbial counts, which helps maintain the quality of the dates and prolong their shelf-life (Gil et al. 2009).

Dates are usually cleaned in a washer that has sprinklers and rotates in a circular motion. They are then dried using a hot air blower system in a clean and sanitary environment (Sindh 2010). It is important to wash them with sanitizers in order to remove any dirt or debris, and to disinfect the water so as to prevent any contamination between clean and contaminated products. A significant portion of the plant floor will be dedicated to manual labor, and the dates will go through another inspection process before being packed in large quantities (Fig. 4).

After being washed, dates are subjected to hot air to eliminate any additional moisture on their surface. Subsequently, a heat treatment of 60–65 °C is utilized as a form of partial pasteurization to restrict the proliferation of microorganisms,

**Fig. 4** Dates grading for size and quality inspection prior to bulk packing. *Source* Dates Processing Factory, Ministry of Agriculture, Alahsa, Saudi Arabia (2002). *Source* AlKhateeb and Dinar (2002)

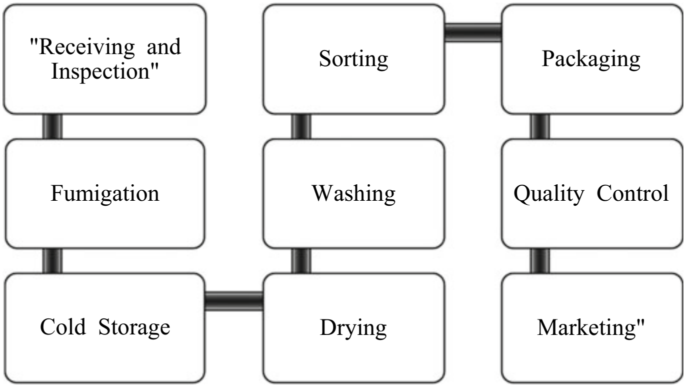


**Fig. 5** A flow chart of common processes for dates processing

enzymes, and insects (Ashraf and Hamidi-Esfahani 2011). It is recommended to store dates with a moisture content between 24 and 25%. Maintaining a water activity level between 0.6 and 0.65 aw is necessary to preserve their quality and chemical stability (Aleid 2013). Dates harvested in Saudi Arabia, which are processed with proper hygiene measures and packaged adequately, hold significant potential in both the domestic and international markets. The process involved in date processing includes fumigation, washing, sorting, grading, glazing, weighing, and packaging. Figure 5 presents a flow chart illustrating the various steps of date processing in Saudi factories.

High-quality dates are usually prepared for sale at processing plants in Saudi Arabia. This process involves vacuum packaging whole dates, either compressed or non-compressed, using either flexible sealed plastic coverings (Alhamdan and Hassan 1999) or polyethylene-polyamide (PE-PA) bags. Vacuum packaging is an effective method for preventing the darkening of dates during long-term storage (Mohsen et al. 2003). However, loose dates are packed differently—cleaned and graded dates are weighed and then packaged in cardboard boxes. The weight of these boxes typically varies from 1 to 20 kg, depending on the specific requirements of domestic or international customers.

The storage period for dates in Saudi Arabia lasts a long time, typically from 10 to 12 months. The temperature is one of the most crucial factors that affect how long fresh dates can be stored and maintains their quality. The Food and Agriculture Organization (FAO) has developed various methods to extend the storage of dates by using refrigeration or freezing. This process mainly focuses on slowing down the ripening of the fruit. Most dates are harvested when they are fully matured, known as the tamar stage. At this stage, the color and sugar content representing the specific date variety are fully developed. Furthermore, the tamar stage fruit possesses the highest potential storage lifespan, enduring for many months in contrast to rutab or khalal stages, which typically endure for only several days to a few weeks, at most.

Fresh dates that are harvested at the tamar stage and stored at a temperature of – 18 °C offer the best economical extension of shelf life and preserve the quality of the edible product (FAO 2008).

Dates in Saudi Arabia may need to be stored for long periods, up to about 10–12 months. The temperature is the most important factor that affects how long fresh dates can be stored and the quality they maintain. The Food and Agriculture Organization (FAO) has developed various methods to extend the storage of dates by using refrigeration or freezing. This process mainly focuses on slowing down the ripening of the fruit. Most dates are harvested when they are fully matured, known as the tamar stage. At this stage, the color and sugar content representing the specific date variety are fully developed. Additionally, the tamar stage fruit has the longest potential storage life, lasting for many months compared to rutab or khalal stages, which only last for several days to a few weeks at most. Fresh dates that are harvested at the tamar stage and stored at a temperature of – 18 °C offer the best economical extension of shelf life and preserve the quality of the edible product (FAO 2008).

## 4.4 *Value Added Products from Dates*

### 4.4.1 Date Paste

Date paste can be used in the baking industry as a filling in pastries and biscuits, as well as an ingredient in cereals, breads, cakes, cookies, and ice cream. The confectionery industry has also incorporated date paste as a significant component (Alhamdan and Hassan 1999). Date paste is derived from steamed and minced date fruit pulp, resulting in a delicately thick texture. It can be employed as a nutritious substitute for sugar in the confectionery and bakery sectors (Siddiq et al. 2013).

When processing date paste, we mix or mince clean-pitted dates while adding a specific amount of steam. A moisture content of 23% (0.06 aw) in date paste is considered the minimum safe limit to avoid microbial spoilage. The extruded date paste is typically packaged in high or low-density polyethylene or polypropylene packages. According to Aleid (2009), the extraction process of date paste from the ‘Khalas’ cultivar resulted in a yield of 90% in kilograms as the final product.

### 4.4.2 Date Syrup

The process of producing date syrup involves several steps. First, the fruits are subjected to juice extraction, filtration, and concentration. To enhance the penetration of water, the dates are crushed using specialized rollers in a pretreatment process. Juice extraction can be done either in batches or continuously, with the latter allowing for a steady and uninterrupted production line (Barreveld 1993). The ratio of water to fruit weight plays a crucial role in extracting solids from the juice, both technically and economically, according to a study by Ramadan (1998). Achieving a ratio of one part pulp to three parts water results in a high recovery rate of total soluble solids, specifically 72% based on fresh basis. Following refinement, the juice attains a soluble solid content ranging from 20 to 25%, requiring further concentration. It is worth noting that the typical soluble solid content found in date syrup is 75%, as indicated by Al-Farsi (2003).

## 5 Red Meat Poultry and Seafood Processing

The red meat industry in Saudi Arabia presents several opportunities for potential market investments because of the high meat consumption. The younger generation, as well as the working-class population, have a demand for frozen meat and food that is ready to eat or cook, containing proper nutrients and boasting an exclusive taste (Research and Market 2023). Additionally, there is a need for increased attention from meat processing facilities in Saudi Arabia in terms of disinfection and hygiene practices at various stages of the red meat, poultry, and seafood supply chain.

### *5.1 Red Meat and Poultry Market in Saudi Arabia*

According to a report from Mordor Intelligence (2021a), the edible meat market in Saudi Arabia is divided into different types of meat, including poultry, beef and veal, mutton, and other kinds of meat. Additionally, the market is segmented based on storage types, categorizing edible meat as chilled, frozen, and shelf stable/fresh meat. Over the forecast period from 2020 to 2025, the edible meat market in Saudi Arabia is projected to experience a compound annual growth rate of 5.5%. Several key factors contributing to this growth include a strong economic expansion, changing consumer preferences, and advancements in technology. The country's robust economic growth has resulted in increased protein consumption, driven by a growing domestic and expat population. Furthermore, there is a rising preference for red meat, both sheep and bovine meat, which also plays a role in driving the meat market in Saudi Arabia (Mordor Intelligence 2021a).

The frozen meat experienced the fastest growth rate because it has a longer shelf life, which is a significant characteristic that supports the frozen meat market. Additionally, the credibility of Saudi manufacturers of Halal food, particularly frozen meat and meat products, has contributed to the expansion of food processing facilities in the country. Moreover, lamb that is imported is mainly sold through the retail sector. Consumers showed the highest interest in frozen or chilled lamb meat, which includes cuts like the leg, shoulder, and carcasses. Furthermore, Saudi Arabia has established very high Halal standards through the Saudi Food and Drug Authority (SFDA), making its food products appealing to Muslim countries (Research and Markets 2022, 2023).

Red meat is a necessary part of the diets of Saudi Arabian consumers, and it plays a significant role in the country's economy. The government of Saudi Arabia provides interest-free loans and discounts on the purchase of certain cattle equipment. When catering to government institutions such as hospitals, schools, and universities, it is required to use locally sourced ingredients for over 70% of the menu. This initiative aims to increase domestic meat production, which in turn contributes to the growth of the red meat market. Consumers in Saudi Arabia prefer to buy fresh meats from retailers due to their traditional habits and belief in the cost-effectiveness and reliability of these sources. Additionally, the presence of slaughterhouses for goats, sheep, cows, and camels, as well as specialty retail stores, further stimulates sales in the respective segments as illustrated in Table 2 (Research and Markets 2023). Red meat operations at retail stores engage in activities such as "cutting up, slicing, and trimming carcasses, halves, quarters, or wholesale cuts into retail cuts such as steaks, chops, roasts, grinding and wrapping meat products, and ground beef" (AskUSAD 2021). Beef is often chopped or ground, with or without seasoning, and without the addition of beef fat or processed into beef patties. Poultry manufacturing premises produce various meat cuts, including whole legs with bone or boneless breasts, minced meat, and drumsticks. However, over 80% of locally-sourced chicken meat is sold chilled.

In 2020, Saudi Arabia made significant progress in achieving self-sufficiency in the red meat industry (Fig. 6). However, despite these advancements, the country still imported 70% of its red meat demand in the same year. In 2019, the red meat import was 51.7% from Brazil, 9.9% from Australia, 7.4% from India and 3.1% from others (Ministry of Investment 2021). In 2021, the Saudi Agricultural and Livestock Investment Company (SALIC) announced the news of its merger with Minerva Foods factories in order to establish a firm known as Minerva Foods Australia. SALIC, which possesses 35% of the company, has the capability of producing annually one million of livestock and aimed to manufacture and promote red meat (sheep meat) globally and more specifically into the regions of the Gulf and Middle East (Mordor Intelligence 2021a).

The poultry market in Saudi Arabia is divided into different categories such as eggs, broiler meat, and processed poultry, as well as distribution channels like hotels, catering, restaurants, hypermarkets/supermarkets, and other channels. According to a report from Mordor Intelligence in 2021, it is expected that the Saudi Arabian

**Table 2** Livestock slaughtered under the supervision of the municipalities by region and type (2019)*

| Region | Source | Goat | Sheep | Cow | Camel | Total |
|---|---|---|---|---|---|---|
| Grand total (million) | Local | 1.88 | 4.02 | 0.10 | 0.29 | 6.30 |
| | Import | 0.63 | 2.65 | 0.14 | 0.07 | 3.49 |
| | Total | 2.51 | 6.67 | 0.24 | 0.36 | 9.78 |

*Source* Ministry of Municipal and Rural Affairs
*Slaughter under the supervision of the municipal

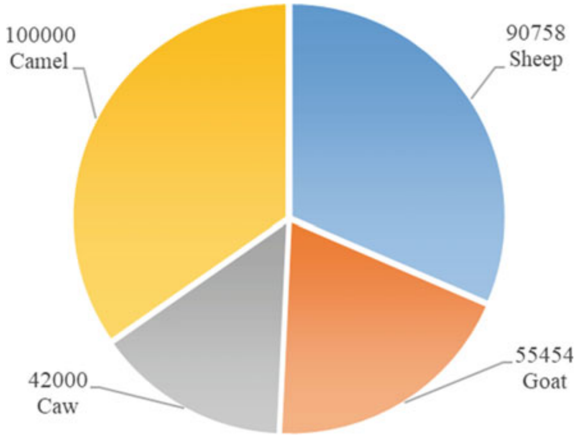


**Fig. 6** Red meat production in Saudi Arabia in 2019 (metric ton). *Source* FAO (2023), https://www.fao.org/faostat/en/#data)

poultry market will experience a Compound Annual Growth Rate (CAGR) of 3.53% from 2022 to 2027. To increase profit margins, many poultry producers have shifted from producing frozen chicken meat to chilled products. This is partly due to the fact that chilling helps avoid freezing and cold storage costs. The United States Department of Agriculture (USDA) reported that in 2020, Saudi Arabia ranked as the fourth largest importer of broiler meat globally, along with the European Union. In that same year, Saudi Arabia imported a total of 619,788 metric tons of chicken meat and products, with Brazil being the main supplier at 71.12%. This indicates the increasing demand for poultry products. In 2020, poultry production in Saudi Arabia reached 900,000 metric tons, as stated in Fig. 7. The Ministry of Environment, Water, and Agriculture (MEWA) reported that domestic production in Saudi Arabia achieved a self-sufficiency level of 60% in the same year. Furthermore, the Saudi Arabian government has set a strategic objective to increase self-sufficiency in the local demand for broiler meat within the next five years. As a result, the market for broiler meat is expected to grow during the forecast period according to Mordor Intelligence (2021b).

## 5.2 *Red Meat and Poultry Consumption in Saudi Arabia*

Saudi Arabia is one of the highest consumption of red meat in the Middle East and North Africa region. However, Saudis prefer lamb meat above beef and veal, consuming 5.32 (kilogram per capita of sheep in 2017 and 3.91 kg per capita of beef and veal in the same year (Ministry of Investment 2021). Although the majority of poultry meat consumption is in the form of whole broilers, there is a growing demand for processed chicken meat. This increase is primarily driven by fast food restaurants and individuals or couples who prefer ready-to-cook poultry meals. In recent years, there has been a rise in preference for specific cuts of poultry meat, such as whole

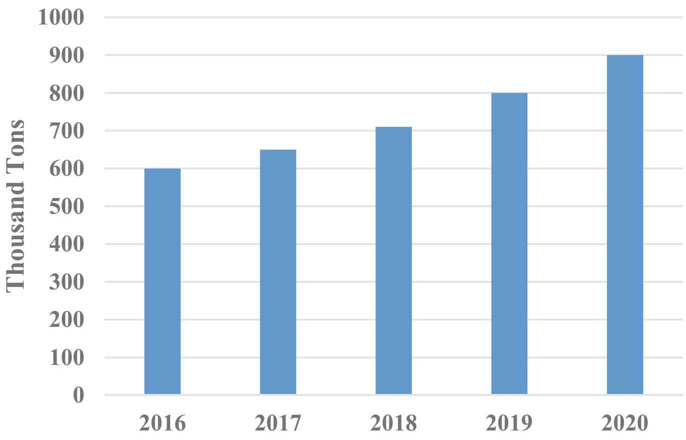


**Fig. 7** Poultry meat production in Saudi Arabia (metric ton). *Source* FAO (2023), https://www.fao.org/faostat/en/#data

legs, boneless breasts, minced meat, and drumsticks. The lower price of poultry meat compared to other meats contributes to its popularity in banquets and catering services, which is expected to stimulate market growth. In Saudi Arabia, chicken is considered an essential food item. Studies indicate that beef, lamb, and fish are considered luxury items, while chicken is considered a necessity. Saudi consumers have a preference for locally sourced fresh chicken meat, with over 80% being sold as chilled products. Saudi residents consumed 45.12 kg of poultry per capita in 2017.

### *5.3 Red Meat and Poultry Processing in Saudi Arabia*

The major characteristics of importing frozen meat to Saudi Arabia are ease of incorporation and longer shelf life. Consumers in the country prefer imported frozen or chilled lamb meat, which is typically cut into leg, shoulder, or kept as whole carcasses. This type of meat has witnessed the strongest appeal among consumers (Samiksha 2020). In retail stores, red meat operations involve cutting up, slicing, and trimming carcasses, halves, quarters, or wholesale cuts. These are then turned into retail cuts such as steaks, chops, roasts, and ground meat products, which are wrapped for sale. Ground beef is heavily consumed in Saudi Arabia. Beef is chopped or ground, with or without seasoning, and without the addition of beef fat. It is important that ground beef does not contain more than 30% fat. Ground meats are processed to beef patties. Ground poultry meat also chopped or ground without the addition of water, cereal, soy derivatives, or other extenders and sold as fresh or frozen (Association of Food and Drug Officials 2011). More focus from meet processing facilities towards disinfection and hygiene practices in different stages of meet supply chain as could be seen from Table 3.

**Table 3** Red meat value chain analysis. Carcasses

| | **Live Cattle** | **Carcasses** | **Unprocessed meat** | **Processed meat** |
|---|---|---|---|---|
| Distribution | Selling livestock to meat processing companies | Slaughtering of livestock in own or municipality slaughterhouses and selling of carcass | Cutting carcasses to meat cuts (e.g. minced, chopped, steak) | Processing meat through salting, curing, smoking to enhance flavor or improve preservation |
| Product category | Live cattle (vealers, feeders, heifers, culled cows, angus) | Carcass (feeders, heifers, culled cows, angus) | Fresh meat cuts (feeders and angus) | Hotdogs, sausage, burger and other products |
| Sales channels | BTB: meat wholesalers | BTB: meat processing companies, butchery shops, hotels, restaurants and catering | BTC: in butchery shops or modern trade<br>BTB: modern trade chains or hotels, restaurants and catering | BTC: in grocery shops (modern and traditional) |

*Source* Ministry of Investment (2021)

**Table 4** Fish and shrimps production in metric ton (thousand)

| | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|
| Fishing of Red Sea | 23.0 | 23.4 | 23.3 | 24.0 | 24.2 |
| Fishing of Arabian Gulf | 41.8 | 42.2 | 43.1 | 44.0 | 42.0 |
| Production in fish farms | 38.8 | 40.3 | 55.0 | 72.3 | 75.3 |
| Total | 103.6 | 105.9 | 121.4 | 140.3 | 141.5 |

*Source* The joint technical team from the Ministry of Environment, Water and Agriculture and the General Authority for Statistics

## *5.4 Seafood Market in Saudi Arabia*

It is predicted that the fisheries and aquaculture market in Saudi Arabia will experience a compound annual growth rate (CAGR) of 4.1% from 2020 to 2025. This growth can be attributed to the implementation of strict product safety and traceability standards, utilization of advanced technology, and the enforcement of rigorous biosecurity measures. Over the past few years, there has been a significant increase in domestic aquaculture production, unlike capture fisheries which have seen a decline in landings. Despite the growth in domestic aquaculture, Saudi Arabia still heavily relies on imports to meet its domestic demand for fish and fish products. These imports are mainly sourced from developing countries in South and Southeast Asia, South America, and Africa, according to a report by Mordor Intelligence in 2023. Saudi Arabia primarily imports "processed fish, shrimps, lobsters, caviar, cuttlefish, sardines, salmon, and tuna from countries such as Korea, Thailand, the Philippines, India, Bahrain, Bangladesh, the United Arab Emirates, and Malaysia" (Mordor Intelligence 2023).

Seafood supply from the local fisheries over the period 2015–2019 can be seen from (Table 4). Aquaculture has shown a steady increase in production levels, rising from 38,000 tons in 2015 to 75,000 tons in 2018.

Since 2018, domestic aquaculture production has exceeded capture fisheries landings. Shrimp is the predominant product of the aquaculture industry in Saudi Arabia. Most of the farmed shrimp produced is exported, while the majority of the farmed fish is consumed domestically (Eurofish International Organization 2022).

## *5.5 Seafood Consumption in Saudi Arabia*

The country relies on imports to meet its domestic need. According to a report by Mordor Intelligence in 2023, it is predicted that the domestic consumption of fish in Saudi Arabia will increase by 5% each year until 2030. In an effort to stimulate investment and growth in the domestic aquaculture industry, Saudi Arabia has set a production target of 600 thousand tons annually by 2030. Over the past three years, the average amount of seafood imported into Saudi Arabia has exceeded 200,000 tons, with a value of approximately 2.5 billion Saudi Riyals. On the other hand, Saudi Arabia's seafood exports have averaged around 65 thousand metric tons, with a trade value of up to one billion Saudi Riyals, as reported by Hasan (2019). The demand for seafood in Saudi Arabia has increased significantly, with a rise in consumption observed in 2018, particularly with the increased import of Norwegian salmon, as many Saudis seek healthier alternatives to chicken and meat. The per capita fish consumption in Saudi Arabia has also risen from 6.4 kg in 1997 to 11.3 kg in 2017, with an annual growth rate of 2.9%, surpassing global, regional, and sub-regional averages. The average per capita global fish consumption currently stands at 19 kg.

According to the FAO (2022), Saudi Arabia's population is expected to increase from 34.269 million in 2019 to 39.322 million in 2030. This would require an additional 57,287 tons of fish to maintain the per capita fish consumption at the current level of 11.3 kg. However, if Saudi Arabia aims to increase its per capita fish consumption to 16.4 kg by 2030 (based on historical trends), the total fish demand would increase from 256 to 438 tons between 2019 and 2030. Although the aquaculture growth in Saudi Arabia can cover the extra fish demand driven by population growth, it will not be sufficient to meet the additional demand caused by both population growth and higher per capita fish consumption. In order to generate enough supply to meet this demand, the country's aquaculture sector needs to grow by 14.4% annually between 2019 and 2030 (FAO 2022).

## 5.6 Seafood Processing in Saudi Arabia

The Saudi Food and Drug Authority (SFDA) has implemented strict inspection and regulatory measures on seafood. These measures are aimed at reducing the practice of dumping and improving the safety and quality of imported seafood. Additionally, the SFDA aims to address any potential biosecurity risks that may be associated with products coming from specific countries. The final products from the seafood industry are of superior quality and are certified under the national aquaculture quality certification and labeling program, known as SAMAQ (Saudi Mark of Aquaculture Quality), as stated by Eurofish International Organization (2022).

Seafood spoilage is mainly imitated by chemical, enzymatic or microbial activities are responsible for loss of fishery products every year (Kelvin and Reza 2022). The process of fresh fish spoilage is very rapid, and rigor mortis usually begins within 12 h of storage at high temperatures (Berkel et al. 2004). As spoilage progresses, a sickly sweet smell develops, followed by a stale-fish odor, which is caused by the formation of trimethylamine. Eventually, there is a release of ammonia odor, which is then followed by putrid odors due to the presence of $H_2S$ and indole compounds (Erkmen and Bozoglu 2016). Ensuring food safety and preventing detrimental changes in texture, color, and flavor caused by bacterial growth and chemical/biochemical activity can be achieved by quickly cooling/freezing the fish and storing it at stable low temperatures.

In terms of ensuring food safety, the Hazard Analysis Critical Control Point (HACCP) concept serves as a risk management program for food processors. Its purpose is to prevent, eliminate, or decrease the level of potential food safety hazards that may exist in fishery products (FDA 2011). The accompanying programs that support HACCP include "Good Manufacturing Practices" (GMPs) and "Sanitation Standard Operating Procedures" (SSOPs) (Seafood HACCP Alliance 2011). Both the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) have integrated the HACCP and GMP programs into a Code of Practice for Fish and Fishery Products. This code offers "guidance and recommendations on the growing, harvesting, handling, storage, transportation, and retail sale of fish, shellfish, and aquatic invertebrates" (WHO 2021).

The most commonly sold fish and seafood retail category in Saudi Arabia is whole fresh fish. Customers typically ask the fishmonger to fillet the fish and remove any stray fine bones. Fish processing in Saudi Arabia follows a similar process as described by Ghaly et al. (2013). This includes stunning the fish, grading, removing slime, scaling, washing, beheading, gutting, cutting fins, slicing into steaks, filleting, separating meat from bone, labeling, and distributing. To ensure seafood safety and freshness, the following factors should be checked upon receipt: product temperature (chilled seafood should be below 5 °C, but ideally between − 1.5 and 2 °C; frozen seafood should be below − 18 °C), package condition, hygiene and cleanliness of the transport vehicle, and visual quality criteria. Seafood should never be kept at room temperature to prevent spoilage. Low storage temperature helps extend shelf life by minimizing the activity of enzymes and the growth of bacteria. Seafood can be safely stored in ice, a chiller, cool room, refrigerator, freezer, or refrigerated display cabinet (Department of Fisheries 2002). The Saudi Food and Drug Authority (SFDA) enforces rigorous inspection and regulatory measures on seafood, aiming to reduce dumping and improve product safety and quality.

## 6 Food Cold Chain in Saudi Arabia

Owing to the arid climatic conditions in Saudi Arabia, majority of the food require efficient cooling or freezing systems including meat and seafood, fruits and vegetables as well as dairy products. An effective supply chain is crucial in reducing high post-harvest losses. This chain is responsible for providing storage facilities and proper cold chain for various food products, which in turn helps stabilize food prices in Saudi Arabia. There are several factors that affect food consumption in Saudi Arabia, such as quality, production, storage, nutritional value, and consumer health. Addressing these factors can result in a reduction of food loss and waste. It is important to highlight the significance of having efficient cold storage facilities, as they directly impact the food security index. However, Saudi Arabia remains vulnerable to potential food shortages in the future. Additionally, it should be noted that food security pressures in Saudi Arabia are lower than the global average, particularly in terms of water resources.

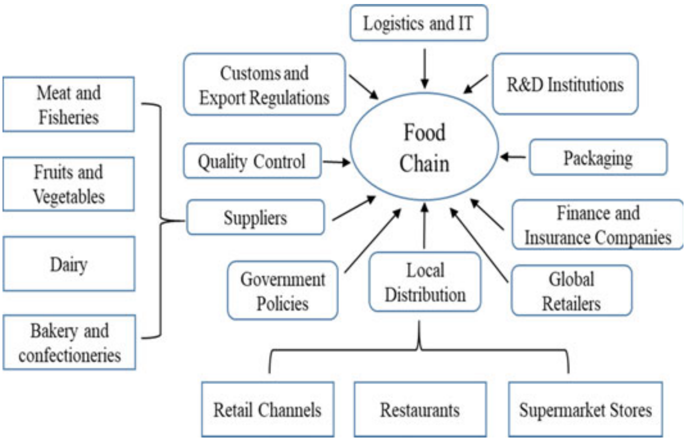


**Fig. 8** Cold supply chain cluster with all Stakeholders in Saudi Arabia. *Source* Joshi et al. (2018) with some modification

The cold chain is a temperature-controlled food supply chain for storing and distributing cold or frozen agricultural products, which is positively reflected in extending the shelf life (Joshi et al. 2018). The cold supply chain cluster with all Stakeholders in Saudi Arabia could be seen from Fig. 8.

Owing to the arid climatic conditions in Saudi Arabia, majority of the food require efficient cooling or freezing systems including meat and seafood, fruits and vegetables as well as dairy products. There is particularly very high demand for cold chain facilities during Hajj and Ramadan and the storage facilities across the country usually witness maximum capacity utilization during this period. The booming dairy products accounted for the largest contribution to the revenue of the cold chain industry in Saudi Arabia and demanded the growth of cold chain facilities in the country. Meat and Seafood was analyzed to be a significant revenue contributor due to the rising exports and imports from the country. The remaining share was contributed by fruits, vegetables, and other products such as bakery and confectionery, processed foods and ready-to-eat meals that are usually imported into the Kingdom. In the future, it is expected that the revenue of the Cold Chain market in Saudi Arabia will increase at a compound annual growth rate (CAGR) of 11.2% from 2018 to 2023. The growth in the market is due to an increase in the dairy industry and a rise in food imports (Payal 2020).

### *6.1 Measures and Challenges Facing Food Cold Chain in Saudi Arabia*

According to Aleid (2020) there are several factors to consider when it comes to distributing food in Saudi Arabia to maintain the quality of the product. These factors include ensuring that the color, texture, and nutritional value of the food are preserved, extending the shelf life of the products, promoting the growth of the packaging industry, addressing the issue of traceability, improving handling and hygiene practices, managing inventory effectively, and implementing automation in the distribution process. Additionally, the refrigerated transport industry is experiencing significant growth in Saudi Arabia. However, there are also challenges that need to be addressed in the cold chain supply in Saudi Arabia. These challenges include achieving a balanced distribution of cold storage facilities, dealing with the high costs of implementing smart systems for monitoring and optimizing processes, facing the rising costs of real estate, making costly long-term investments that may take time to generate profits, dealing with high energy consumption costs, and bearing the expenses associated with transportation, distribution, and storage (which amount to 25 USD per metric ton per month) (Aleid 2020).

There are various strategic measures that need to be considered to overcome the challenges faced by the cold chain supply in Saudi Arabia. These measures include developing business models that promote producers owning their supply chains, continuing existing grants and subsidy schemes for cold chain infrastructure, developing and expanding the logistics and transport sector, and establishing multimodel cold chain links through railways. Additionally, it is important to focus on fast-tracking perishable goods and attracting foreign investments (Aleid 2020).

## 7 Food Control System in Saudi Arabia

The Saudi Food and Drugs Authority (SFDA) is responsible for controlling, examining, and protecting consumers from any serious health issues (Jadi 2016). Several reforms are being implemented by the Saudi Food and Drug Authority (SFDA), a central authority established in 2004 (Bawazir 2014), to ensure the establishment of a high-quality food and drug policy for consumer safety. The Saudi government considered centralizing food control activities and restructuring various established controlling institutions (Al-Kandari and David 2012) to bring them under one strong organization. SFDA is responsible for testing and evaluating imported food products through air, land, and sea transportation (Al-Kandari and David 2012). Some of the departments in charge of food control and analysis laboratories are listed below, which encompass various activities and processes (Al-Kandari and David 2012; Jadi 2016).

Such as:

(a) The Sample Receiving Department needs to consider the rules and regulations when receiving samples of food and drug products.
(b) The Chemical Analysis Department analyzes the levels of chemical contamination and accuracy of food and drug products.
(c) The Microbiological Department analyzes meat, poultry, and baby food products.

(d) The Food Irradiation Testing Department checks the background of food supplied or imported from different destinations.
(e) The Standardization and Meteorology Department ensures compliance with international standards and local policies regarding safety and usage.
(f) The Quality Assurance Department ensures that the product is genuine and suitable for the customer.
(g) The Research Department investigates the advantages and disadvantages of imported products sold to the public.

The food exporters to Saudi Arabia should collaborate closely with local importers in order to adhere to the food import regulations established by SFDA. They should also make sure to focus on proper product labeling and preregistration and approval processes. This will not only help ensure smooth imports but also reduce the likelihood of rejections at the ports of entry in Saudi Arabia. In the Food Processing Ingredients-Saudi Arabia (2018) report, it is mentioned that numerous local producers are enhancing their food quality assurance by obtaining ISO certifications and creating their own food safety management systems, such as HACCP programs.

## *7.1 Saudi Arabia National Halal Food*

The Saudi Arabian halal food market is currently valued at $6 billion, but it has the potential to capture a much larger portion of the $1.3 trillion global halal market (Al-Ghalayini 2019). According to the Saudi Gazette (2018), the SFDA (Saudi Food and Drug Authority) has announced a plan to establish a halal food center. This initiative is in line with the objectives of the Kingdom's Vision 2030, which highlights Saudi Arabia's importance in the Arab and Islamic world, as well as its advantageous geographic position that connects three continents. The center will offer a range of services, such as issuing certificates for halal food products and establishments. Additionally, it will acknowledge the institutions responsible for issuing these certificates, and actively cooperate with universities and research centers for further research and studies. The center's strategy focuses on three key points. First, imported products must adhere to halal conditions, and the center will develop quality standards and specifications. Secondly, the center aims to represent the global halal food industry, providing local and international logistic services and establishing connections with relevant agencies worldwide, including those in non-Muslim countries. Thirdly, the center aims to contribute to the strengthening of the economy and provide training opportunities.

The center will allow halal food establishments and products, such as hotels and restaurants, that have been approved to use its logo. It will also offer training to companies and institutions that want to enter the halal industry and establish a referral laboratory for halal food products. In accordance with Shariah guidelines, birds and animals must be slaughtered, and no non-Islamic ingredients will be used

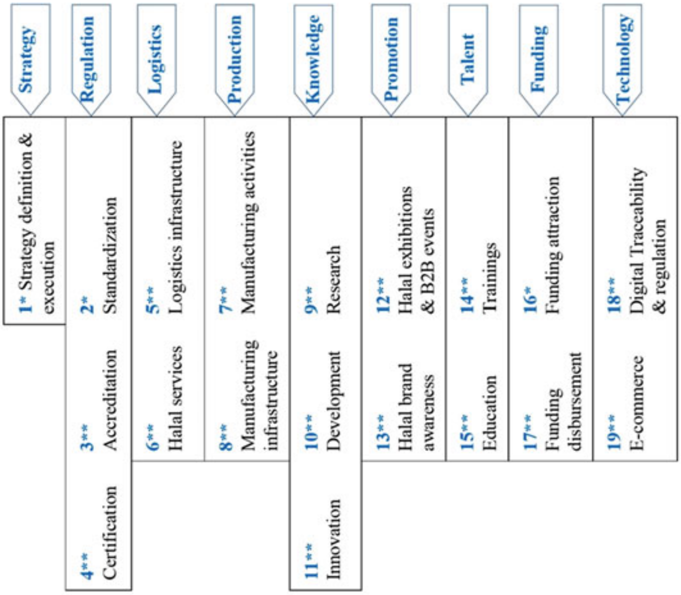


**Fig. 9** Halal ecosystem map in Saudi Arabia. *Coordination roles, **Execution roles. *Source* Saudi Arabia National Halal Strategy Executive Summary, SFDA (2018)

in the production and processing of food items. This center has been created with the aim of fulfilling the goals of the national transformation program. Saudi Arabia has a rich set of entities that naturally fulfil roles across 8 functions and 19 roles were identified for the halal ecosystem to function efficiently as could be seen from (Fig. 9).

## 8 Foreign Investment in Saudi Food Processing Sector

The Saudi food processing industry, which is growing rapidly, has attracted multinational corporations to set up production facilities in Saudi Arabia (Saudi Gazette 2018). The revised Saudi Foreign Investment Act allows foreign investors to fully own food production facilities or collaborate with Saudi partners to establish joint processing facilities. The Saudi Arabian food industry is experiencing significant investments as the country aims to enhance its food security and adapt to technological advancements within the market (Sialparis 2021). As stated by the Saudi Arabia General Investment Authority (SAGIA), Saudi Arabia is expected to receive approximately US$ 59 billion worth of investments in its food industry by 2021 (Al-Ghalayini 2019). Projects that have been approved under the foreign investment act are entitled to equal benefits, incentives, and guarantees as domestic companies. This includes the opportunity to access subsidized loans from the Saudi Industrial Development Fund (SIDF). Foreign companies have the option of getting involved in the Saudi food-manufacturing industry through various means. These options include establishing their own facilities, acquiring or gaining control over existing Saudi companies, forming partnerships with Saudi investors, entering into licensing agreements with local manufacturers, or having Saudi food processors produce goods under their brand names (Food Processing Ingredients-Saudi Arabia 2018).

According to the updated foreign investment act, foreign companies are allowed to take part in the Saudi food-manufacturing industry through various means. These include establishing their own facilities, acquiring or gaining control of existing Saudi companies, partnering with Saudi investors in joint ventures, entering into licensing agreements with local manufacturers, or having Saudi food processors produce goods using their own brand names (Food Processing Ingredients-Saudi Arabia 2018). International partners can experience various benefits by entering into joint ventures with Saudi food firms. One advantage is easy access to the rapidly growing Saudi market, as well as the markets within the GCC region. Many multinational corporations, such as "Mars Inc., Cargill, Delmonte, PepsiCo, Heinz, Danone Ltd., Arla Foods Amba, Fonterra, United Biscuits (UK) Limited, Coro Foods, Lactalis Group, ULKER International, and Alami Vegetable Oil Products Sdn. Bhd Malaysian, have already established joint ventures or owned production facilities in Saudi Arabia" (Food Processing Ingredients-Saudi Arabia 2018).

## 9 Conclusion and Prospects

The food and drink market of Saudi Arabia holds the top position in the Middle East, with a worth of $42 billion. It is predicted to grow at a rate of 3% until 2030. The country is expected to consume 39.0 million metric tons of food by 2023, which shows a yearly average growth of 3.2% since 2018. The food industry of Saudi Arabia is facing several challenges, including the shortage of skilled technologists, cost fluctuations in essential raw materials, increased expenses in the supply chain, and the lack of incentives to support research and development due to the ease of import substitution. The dairy industry heavily depends on imports of cheese, butter, and other solid dairy products unless it can boost its annual production by 450,600 tons over the next ten years.

This reliance could lead to foreign exchange payments of up to US$587 million. As a result of the production of unhealthy food items, the consumption of high-fat and high-sugar processed foods and drinks, and sedentary lifestyles, Saudi Arabia has experienced high rates of obesity and diabetes. Recent reports indicate that 70% of Saudis are overweight, and up to 30% have diabetes. The diabetic rate is expected to double by 2030. The high rates of obesity and diabetes have created opportunities for local food manufacturers to offer a limited range of diet foods, primarily consisting of fat-free and low-fat dairy products. The low demand for diet foods reveals a lack of awareness among most Saudi consumers regarding the benefits and availability of healthy or diet foods. To take advantage of this untapped, potentially significant, and profitable market, local food manufacturers have initiated collaborations with the relevant Saudi government agencies to increase awareness among consumers regarding healthy eating habits. The expected rise in health consciousness is predicted to boost the demand for diet and healthy food products and drinks in the upcoming years.

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# Chapter 19
# Food Safety and Quality in Saudi Arabia

**Maisa Bushra Omer, Dina Omer Mohamed Ali, Hattim Makki Mohamed Makki, and Ahlam Mohammed Alateeq**

**Abstract** Foodborne diseases are a global threat to both public health and the economy. It is necessary to address the issue of ensuring the quality and safety of food in order to protect individuals from these diseases. Unsafe food products can contain harmful microorganisms or toxic chemicals that can cause a range of diseases such as diarrhea and cancer. Food safety is the primary indicator of sustainable public health and economic progress. Climate changes have an impact on the safety and quality of food, negatively affecting the achievement of food security. Food safety and quality are affected by climatic changes throughout the food supply chain, with varying degrees of risk starting from the production stage and continuing until the final consumption of food products. This exacerbates the possibility of food disease transmission and the increased toxicity of microorganisms that cause these diseases.

M. B. Omer (✉) · D. O. M. Ali
Department of Food and Nutritional Sciences, College of Agriculture and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: mbahmed@kfu.edu.sa

D. O. M. Ali
e-mail: dali@kfu.edu.sa

M. B. Omer
Department of Food Engineering and Technology, College of Engineering and Technology, University of Gezira, Wad Madani, Sudan

D. O. M. Ali
National Food Research Center, Khartoum, Sudan

H. M. M. Makki
Date Palm Research Center of Excellence, King Faisal University, Al-Ahsa 31982, Saudi Arabia

Department of Food Science and Technology, College of Agricultural Studies, Sudan University of Science and Technology, Khartoum, Sudan

H. M. M. Makki
e-mail: hmakki@kfu.edu.sa

A. M. Alateeq
Department of Food and Nutritional Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: ahlamalateeq92@gmail.com



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Additionally, food may be endangered by chemical hazards resulting from the use of pesticides, mycotoxins, and heavy metals. Food safety must also be maintained in the face of weather changes, high temperatures and the frequency of extreme weather events such as torrential rains, storms, hurricanes and floods.

**Keywords** Climate change · Food safety · Foodborne illness · Food hazards · Food regulation

# 1 Introduction

Ensuring the survival of human life is mainly dependent on food. Food provides the basic elements that the human body needs to provide energy and to carry out daily activities, as well as to maintain human health. Additionally, food plays an important role in the culture of society and its food identity. Eating food with different tastes and flavors provides a variety of sensations and experiences that should be enjoyed with safe, healthy food. All actors in the food supply chain, from production and harvesting to post-harvest transactions, handling, processing, and distribution, should play their assigned roles in preserving the safety and quality of food. This is to prevent food poisoning and foodborne diseases that could pose a threat to human health. Recently, directly and dramatically, global food trade has increased, making food safety more important than ever. By increasing awareness and understanding of food safety principles, individuals can make informed decisions to avoid any potential inconveniences. To maintain food safety, it is essential to be aware of potential risks that can affect its safety and stability. Contaminations at any stage of the food supply chain, whether biological, chemical, physical or radiological, can negatively affect food safety and lead to food-borne illnesses or injuries. Proper management and effective food safety control are essential to prevent such issues (Hanson 2021).

# 2 Concepts of Food Quality and Safety

## *2.1 Food Quality and Safety*

The terms "food safety" and "food quality" can be overlapping and sometimes unclear. Food safety concerns all kinds of risks, whether chronic or acute, that may harm the health of the consumer. This is not negotiable. On the other hand, food quality includes all other qualities that affect the value of the product and its acceptability to the consumer. This includes undesirable aspects such as spoilage, filth, discoloration, and unpleasant odors, as well as desirable aspects such as food origin, color, flavor, texture, and processing (FAO 2003).

## 2.2 Food Quality Control

This term describes a regulatory activity that requires national or local authorities to ensure that all foods are safe, fit for human consumption, and comply with safety and quality standards. According to the Food and Agriculture Organization of the United Nations, food quality is a very complex matter that determines the value of food and its acceptability for consumers. This includes the nutritional value of the food, as well as its sensory and functional properties. Safety is also an important aspect of food quality, as safe food must be free of pathogenic microorganisms or substances that may harm and affect human health (FAO 2003).

Previously, responsibility for food safety was limited to hunter-gatherers and their families. As communities grew larger and commercial networks multiplied, food safety became more complex and responsibility between more parties expanded (Gorris 2005). This led to the development of quality control (QC), which focuses on meeting quality requirements such as those set forth in ISO 9000:2000. Quality control now includes various techniques and activities aimed at ensuring that a product or service meets specific needs (Alli 2003).

## 2.3 Quality Assurance (QA)

It is part of quality management, ensuring quality requirements as defined in ISO 9000:2000. This includes all planned or systematic actions necessary to ensure that a product or service meets quality requirements. The quality assurance system is applied at all stages of the food production chain, starting from raw materials and extending to manufacturing, selling shops, consumption by consumers and storage. In other words, the application of the quality assurance system may extend from the stage before food raw materials enter the factory until after they are distributed. The ultimate goal of applying the quality assurance system is to provide all the appropriate conditions required for the production of high-quality food that meets the requirements and desires of the consumer (Alli 2003).

## 2.4 Quality Policy

These are the terms, directives, systems and regulations established by the facility or an organization in the context of quality, which have been prepared in advance by senior management and specialists, taking into account the technological aspects, market trends and management's long-term goals (Madhvi 2015).

### 2.5 *Total Quality Management*

Total Quality Management (TQM) is a management philosophy that is grounded in the tenets of quality control. It involves the amalgamation of all operations and procedures within an entity or establishment to attain uninterrupted enhancement of the excellence of products and services. A Quality Management System (QMS) can be described as a collection of harmonized tasks that direct and regulate an organization to elevate the standard of efficiency and proficiency in execution (Madhvi 2015).

## 3 Principles of Total Quality Management

The main objective of the total quality management system is to achieve customer satisfaction and gain their trust by involving every individual who deals directly or indirectly with the manufacture of products. Total Quality Management operates principles: To ensure high-quality operations in an organization or facility, it is important to involve all persons associated with it, including individuals, customers, and suppliers. All administrative departments should participate according to their responsibilities and assigned tasks. Operations are often the root cause of problems, so it's essential to focus on them. Every employee is responsible for maintaining quality, and it's crucial to understand that everyone is both a customer and a supplier. Preventing problems before they occur is key, and all operations related to preparing and delivering products and services to customers must be included in quality improvement efforts. Continuous improvement procedures must be followed, and quality should be managed effectively. Planning and organizing for quality improvement is essential to ensure that the organization or facility meets high standards and delivers high-quality products and services to its customers (Madhvi 2015).

## 4 Implementing Total Quality Management

To establish and achieve total quality management, it's necessary to follow ten basic principles. Firstly, innovative strategic thinking is required to identify opportunities and implement effective solutions. Secondly, businesses must accommodate their customer base by understanding their needs and preferences. Thirdly, identifying and prioritizing real customer needs is crucial to meet their expectations. Fourthly, the focus should be on prevention rather than corrective action to eliminate problems from the root cause. Fifthly, reducing stationary waste is important to optimize resources and minimize costs. Sixthly, following up on continuous improvement processes and procedures ensures that the organization stays on track to achieve its goals. Seventhly, a clear approach to improving the production process should be followed to enhance efficiency and effectiveness. Eighthly, minimizing differences in processes and procedures helps to ensure consistency and reliability. Ninthly, working to develop a balanced approach that considers all aspects of the organization is vital. Finally, applying these principles to all organizational functions ensures that quality is maintained throughout the establishment. By following these principles, an organization can establish and maintain total quality management (Madhvi 2015).

## 5 Food Safety Programs

Food safety programs are made up of methods that are put in place to make sure that the food eaten by consumers is safe and does not harm their health in any way. These methods are designed to prevent any kind of chemical, viral, or microbiological contamination. They include Good Manufacturing Practices (GMP) and Hazard Analysis and Critical Control Points (HACCP). It is worth noting that some programs are optional and are implemented by workers in the food supply chain, while others are mandatory due to legal regulations. To guarantee food safety, safety assurance systems have been established, and these are classified as either mandatory or voluntary based on the risk-free product safety requirements stated by the law.

### *5.1 Good Manufacturing Practices (GMP)*

GMP is a set of guidelines and directives that define the activities that must be carried out and the conditions that must be performed in and during food processing operations in order to ensure that the food produced meets food safety standards locally and globally. The GMP program consists of a set of principles and rules that must be adopted by food industries to ensure the healthy quality of the products. On other hand Good Health Practices (GHP) which is a set of guidelines and guidelines that specify the regulations that must be followed and the sanitary conditions that must be met and monitored at all steps of the food chain in order to ensure food safety.

The HACCP plan is a proactive and preemptive scheme established with a method to guarantee food safety by recognizing and regulating all health hazards related to the food production process. The plan relies on seven fundamental tenets, created to manage biological, chemical, and physical threats from the initial raw material production stage to the final product's distribution and consumption. HACCP is extensively acknowledged as the most effective approach to ascertain product safety and is globally accepted as a mechanism to manage food safety hazards. The HACCP system, which stands for Hazard Analysis and Critical Control Points, is a food safety management program based on seven fundamental principles. The first principle involves performing a risk assessment to determine potential hazards that may arise during the food production process. The second principle requires identifying critical control points (CCPs) where measures can be put in place to prevent or eliminate these hazards. The third principle entails setting and defining critical limits for each CCP, which are the thresholds that must be met to guarantee the food is safe for consumption. The fourth principle involves establishing control procedures for critical limits to ensure they are consistently met. The fifth principle involves identifying corrective actions that can be taken if a CCP goes beyond its critical limit. The sixth principle involves creating verification and audit procedures to ensure that the HACCP system is functioning effectively, and that the food safety plan is continually being improved. Finally, the seventh principle involves keeping thorough records of all of the above principles to demonstrate compliance with food safety regulations (Madhvi 2015).

Through this system, each product is analyzed during the production process for possible chemical, physical and microbiological contamination. Based on the product's chemical, physical and sensory characteristics mentioned in the product specification, preventive measures and critical control points (CCPs) were described and identified, respectively. Next, critical control limits will be defined for each critical point to allow risk control. Since the possibility of failure always exists, it is necessary to obtain corrective measurements to ensure that the process returns to a controlled mode. Procedures should be put in place to verify critical control points and their records. Once the HACCP plan is in place, the plan is validated and all critical points are covered and monitored according to the HACCP plan through discussions among team members. Finally, the plan will be disseminated to the production team and those responsible for evaluating the product quality in the factory. Internal and external audits must be conducted periodically to maintain continuous improvement in the HACCP plan (Madhvi 2015).

## 6 Food Hazard and Consumer Protection

Food is an essential requirement for the survival and continuation of human life. However, it can also pose various risks, such as the presence of foodborne pathogens that can lead to severe illnesses and even fatalities. In today's world, where food supply chains are globalized, ensuring food safety is crucial for the sustainable development of countries that rely on trade and tourism.

It is worth noting that there is a discrepancy in the definition of "safe food" as there is no consensus on a single definition of food safety. Some people believe that food is safe as long as it doesn't cause any illnesses, while others argue that food is safe only if all the stages of handling, distribution, and storage are carried out correctly with appropriate temperature for each stage of distribution. At the same time, some consumers define safe food as being free from pollutants (Alli 2003). Overall, food safety refers to food being handled appropriately throughout the food supply chain, from the producer to the consumer.

The concept of food safety pertains to ensuring the safety of all transactions in the supply chain, from production to the final consumer, by maintaining the quality and integrity of raw materials and finished products. According to the World Health Organization, this standard sets acceptable limits for potential food safety risks using various techniques and protocols to ensure that food is produced, preserved, handled, and consumed safely and hygienically. Despite these measures, many nations are worried about the spread of foodborne illnesses and their effects on public health.

The consumption of contaminated food heightens the risk of contracting foodborne diseases caused by pathogens. Every year, waterborne and foodborne diseases that cause diarrhea are estimated to cause 2.2 million fatalities, including 1.9 million children. The healthcare expenses related to foodborne illnesses pose a significant economic burden for many countries, but this burden can be substantially alleviated by adhering more closely to food protection and safety principles. Furthermore, the global nature of food supply chains increases the risk of new foodborne illnesses emerging, particularly in developing regions (Al-Subaie and Berekaa 2020).

Foodborne illnesses and infections can result in serious health consequences such as death or long-term negative impacts on human health. In addition, outbreaks of foodborne illnesses can damage industries, including commerce and tourism. Spoilage of food not only results in food waste and expenses, but it also jeopardizes food security and can undermine trade and consumer trust. It is the responsibility of all parties involved in the food supply chain, including primary producers, importers, manufacturers, processors, logistics operators, food handlers, retailers, and consumers, to guarantee that food is safe and appropriate for consumption (Miftahul Rrikil Putra Nasjum 2020).

The Codex Alimentarius Committee on Contaminants in Food sets and endorses maximum permissible levels or guideline levels for naturally occurring contaminants and toxic substances in food and feed. It also prepares lists of naturally occurring pollutants and toxicants to assess potential risks (CODEX ALIMENTARIUS, FAO, WHO 2022).

## *6.1 Type of Hazard*

### 6.1.1 Chemical Hazards

Chemical hazards in food can come from various sources. Natural toxins that originate from molds, plants, and marine organisms, such as aflatoxins found in moldy peanuts, pose a significant risk to human health. Environmental pollutants, including heavy metals and persistent organic pollutants, such as mercury in fish, can also contaminate food and cause health problems. Unauthorized food additives or the misuse of approved additives, such as exceeding the limits mentioned in the standard, can also lead to chemical hazards in food. Residues of agricultural fertilizers and pesticides, as well as their misuse by farmers, also pose risks to human health. Medical drugs and vaccinations given to animals like poultry, cows, goats, and camels can also be harmful when consumed by humans. Finally, food allergies, such as those caused by nuts, lactose, and glutamate, are also considered chemical hazards that can cause severe health issues. It is vital to ensure food safety by taking measures to prevent chemical hazards and mitigate their risks to human health (Hua et al. 2018).

### 6.1.2 Physical Hazard

There are many types of physical hazards. These materials, as mentioned in a study by Asselt et al. (2016), include cut wires, metal needles, sand, soil particles, stones, wood, plastic parts, rubber parts, glass fragments, and hair. Additionally, Kenner (2001) reported finding other physical hazards such as broken glass, stainless steel fragments, steel nails, machine parts, building materials, metal filings, jewelry, ballpoint pens, pencils, paper clips, staples, coins, and screws.

### 6.1.3 Biological Hazards

Biological hazards are a type of food hazard that can cause disease in humans through two different mechanisms. The first mechanism is food infections, which are caused by the multiplication and presence of certain types of bacteria in high quantities in the food, leading to disease. Examples of bacteria that can cause food infections include Salmonella, Shigella, and Campylobacter. The second mechanism is food poisoning diseases caused by toxins produced by microorganisms in the food. Examples of microorganisms that can cause food poisoning diseases include *Clostridium botulinum*, *Staphylococcus aureus, Bacillus cereus*, and Enterotoxigenic *Escherichia coli* (Latronico et al. 2017).

## 7 Responsibility for Food Quality and Safety

Food safety is a concern that affects the entire world. As global trade in food products increases, there is a growing risk of unexpected dangers to food safety. This is due to the fact that the food supply chain is becoming longer and more complex, and responsibility for food quality and safety is shared among many actors in the supply chain (Madhvi 2015). Everyone involved in the food industry, including producers, government and private regulatory agencies, and consumers, is responsible for ensuring food safety and quality. It is essential to have legal and ethical responsibility when providing customers and consumers with food that is safe and meets the appropriate quality standards. The food quality and control departments of food companies are responsible for implementing and using programs and activities with high efficiency to ensure the safety and quality of food. Governments worldwide have initiated food laws and regulations to guarantee the safety and suitability of food for human consumption and to protect consumers from eating unsafe foods and misleading food quality practices. Government agencies must implement laws and regulations that will help in spreading confidence in the quality and safety of food among consumers.

When purchasing raw materials, ingredients and packaging materials used in food production in the food supply chain, customers must ensure that these materials are safe and suitable for use. Consumers must also exercise caution when evaluating food products and follow instructions for handling, storing, preparing and using food products (Madhvi 2015).

## 8 Food Laws and Regulations

Food is subject to a variety of laws and regulations in all countries, which set government standards for food chain operators to follow to ensure food safety and quality. Food laws define all the rules that regulate food production and processing, as well as cover other aspects related to the food trade throughout the food production chain, from animal feed to consumer distribution.

Food laws and regulations consist of specific requirements which may differ from country to country. For instance, in the United States and Canada, food laws and regulations cover various facets of food safety and a few aspects of food quality. Compared to other regions globally, American food laws and regulations are the broadest and most commonly implemented. To effectively employ these food laws and regulations to promote food safety and quality, specialists should acquire a comprehensive understanding of their own country's laws and regulations, as well as those of other countries and their governing regulatory systems (Alli 2003).

For instance, in the United States and Canada, federal and national laws govern general and specific aspects of food adulteration or tampering. Food regulations, on the other hand, enforce these policies as laid out in food laws. The aim of these food laws and regulations is to guarantee that food products are safe for human consumption, free from any harmful factors that could cause injury or harm the consumer's health, and are not falsely represented. These laws and regulations apply to locally produced and imported food products. Imported foods must adhere to the laws and regulations of the country for which they are imported. An example of a food law is the US Federal Food, Drug, and Cosmetic Act (FDCA), which controls the safety and quality of most food products in the United States, and the Canadian Food and Drug Act, which is Canada's primary food law (Alli 2003).

### *8.1 FAO Laws and Regulations on Food Safety and Quality*

Governments have requested the assistance of the FAO in formulating, reformulating, amending, and updating national laws and regulations pertaining to food safety and quality. Additionally, they have asked the FAO to enhance the skills of national personnel to carry out food control in compliance with international law. The following legal assistance provided by a team of legal advisors by the Organization (FAO) who work closely with food safety experts should be taken into consideration, to suit the special needs and legal system of Member States: To ensure the safety and quality of food, it is important to align national legal frameworks with international standards such as the International Food Codex. This will help to establish a consistent and reliable approach to food control systems. An effective method for enhancing food control systems is to promote the acceptance and execution of the HACCP system. This can lead to stronger food control systems, safeguarding consumer health, and facilitating market access and domestic and global food trade. To accomplish this, it is crucial for countries to receive assistance in creating their food control systems and raising awareness of global food safety regulations for stakeholders on a national level through direct collaboration with national officials. Additionally, it is crucial to develop the technical and administrative aspects of food control in different countries to ensure that they have the necessary capacities to effectively implement food safety regulations. Overall, these efforts will help to promote food safety and reduce health problems related to food consumption(FAO and WHO 2020).

## 9 International Bodies Concerned with Food Safety and Quality

Food laws and regulations are usually divided between different agencies and departments in most countries. This results in different roles and responsibilities that lead to insufficient oversight and poor coordination. Their obligation to protect public health may conflict with their duty to promote trade or develop a particular industry or sector (Wilna and Egal 2016).

### *9.1 WHO—FAO Strategies for Enhancing Food Safety*

Food safety regulators across the globe have come to the realization that guaranteeing the safety of food is not solely a domestic issue, but also a matter of concern for international food safety authorities. At its 53rd session in 2000, the World Health Assembly urged the adoption of a worldwide plan to decrease foodborne illnesses and boost food safety protocols. The Beijing Declaration on Food Safety was endorsed in 2007 by a top-tier worldwide assembly that included representatives from fifty nations. In 2006, the Department of Food Safety and Zoonoses at the WHO, in collaboration with various international organizations, organized a global gathering to inaugurate a multidisciplinary reference group for foodborne epidemiology. This group was tasked with developing a strategic framework to estimate the scientific magnitude of foodborne illnesses (Prüss-Ustün et al. 2011). Additionally, they acknowledged the necessity for regular exchange of information regarding food safety matters and rapid access to information in the event of a food safety crisis. To achieve this objective, the WHO and the FAO launched the International Food Safety Authorities Network (INFOSAN). The primary goal of INFOSAN is to promote collaboration among food safety authorities at both national and global levels (Khiyami et al. 2011).

In an effort to advance public health, the World Health Organization has developed a global Food Hygiene Message that outlines five fundamental steps for consumers and the food industry to follow, collectively known as the "Five Keys to Safer Food." These steps include maintaining cleanliness, which includes not only hands but also all food preparation areas; separating raw and cooked foods; properly cooking food, including reheating; keeping food within safe temperature ranges outside of the danger zone of 40–140 F to prevent the growth of bacteria and microbes; and using safe water for drinking and safe raw materials for consumers (Wilna and Egal 2016).

### *9.2 Codex Alimentarius Commission (CAC)*

The Codex Alimentarius Commission (CAC) has the duty of formulating a series of global standards, guidelines, and recommendations for food. Its primary goals are to safeguard the well-being of consumers, establish equitable and consistent practices in international food commerce, and encourage cooperation among intergovernmental and non-governmental organizations involved in food standard-setting. The CAC was established in 1963 by the FAO and the WHO.

## 10 Challenges in Food Safety

Sometimes certain foods that are used as a form of luxury are contaminated with harmful microorganisms that may lead to illness and, in some cases, may be fatal. More care is needed to protect consumers and reduce cases of foodborne illness. As our food production and supply chain undergo significant changes, including an increase in imported foods, new obstacles to food safety are expected to emerge globally. These changes in our food system also have an impact on the environment, which can lead to food contamination. Additionally, the emergence of new and emerging antimicrobial resistance, bacteria, and toxins pose a threat to food safety. As consumer preferences and habits evolve, the demand for different types of food and processing methods may also create new safety challenges. Finally, changes in testing methods for diagnosing foodborne illnesses are also expected to impact food safety efforts (CDC 2023).

## 11 Food Safety in Saudi Arabia

Ensuring food safety is a crucial aspect of supporting sustainable public health and economic growth. Saudi Arabia is home to around 30 million inhabitants, but due to limited agricultural output, roughly 80% of its food needs are met by imports from other nations. This poses significant challenges to both the national and individual economies. Several issues impede food safety in Saudi Arabia, such as inadequate implementation of hazard analysis, a shortage of academic and scientific organizations, insufficient specialized training programs, and limited availability of food safety science programs within the country (Al-Subaie and Berekaa 2020).

### *11.1 Local Bodies in Kingdom of Saudi Arabia Concerned with Food Safety and Quality*

In Saudi Arabia, the responsibility of ensuring the safety and quality of both locally produced and imported food is distributed among numerous governmental and non-governmental organizations. These organizations comprise the ministries of health, agriculture, commerce, and industry, as well as the municipalities and rural affairs departments. Additionally, the Saudi Organization for Standardization, Metrology and Quality organization, as well as the customs clearance agency, are also involved. On the other hand, NGOs play an essential role in ensuring food safety and quality, such as the Saudi society for Food and Nutrition, the Consumer Protection society, and the National Permanent Advisory Committee for Food Safety Regulation.

The Food and Drug Authority (SFDA) is a government organization that has been undergoing a process of development since 2003. Its main objective is to ensure the safety and quality of local and imported food through coordination between different organizations.

There are two main organizations involved in managing food safety operations in Saudi Arabia: The Ministry of Municipal and Rural Affairs and the Saudi Food and Drug Authority. The Ministry of Municipal and Rural Affairs is responsible for preparing food legislation related to health conditions, food and health evaluation regulations, monitoring commercial fraud, and supervising slaughterhouses. Taking samples from food and water, and registering food and health institutions, including inspection and investigation of worker health, disease outbreaks, and licensing activities (Al-Mutairi et al. 2015).

Recently, the municipality has issued specific regulatory guides for health workers and implementation of the HACCP system, as well as other guides for the use of food additives, bacterial poisoning, food safety and instructions for food handlers. The Food and Drug Authority was established to ensure the safety of imported and locally produced food, and to uphold national and international standards. It serves as a central authority uniting efforts to enforce and legislate rules on food safety and health, which were previously performed by various government institutions.

The authority is currently responsible for all issues related to food safety, human and animal medicines, and the safety of biological and chemical materials and foodborne disease surveillance, inquiry systems, retrieval and traceability systems, and food control laboratories for community protection (Elmi 2004; Al-Mutairi et al. 2015). The Food and Drug Authority plays an important role in the country's public health sector by organizing consumer awareness and education campaigns. Since 2011, most of SASO's functions related to food safety legislation, health protection, and promotion of good practices in the local industry, have been transferred to the SFDA. However, the lack of coordination and consistency between organizations often undermines the effectiveness of food safety systems in the Kingdom (Al-Mutairi et al. 2015).

## *11.2 Current Situation of Food Safety in Saudi Arabia*

In Saudi Arabia, food safety and hygiene have become major public health issues, just as they are in many other countries around the world. Some studies have shown outbreaks of bacterial food poisoning and foodborne pathogens, especially during the Hajj and Umrah seasons in the holy city of Makkah, where thousands of Muslims come to perform the rituals of Hajj and Umrah (Bakri1 et al. 2017; Khiyami et al. 2011). Street food trade often thrives in Saudi Arabia during Hajj and Umrah seasons, but unfortunately, many food vendors do not follow proper food safety and hygiene practices, or are unable to turn their knowledge and attitudes into practice. In fact, many food poisonings and illnesses can be prevented by implementing preventive measures, particularly by following hygiene practices during food handling. Therefore, community awareness programs are very important in such cases as they support the implementation of good safety and hygiene practices to prevent foodborne illness outbreaks (Khiyami et al. 2011).

## *11.3 Challenges Facing Food Safety in Saudi Arabia*

### 11.3.1 Food Inspection and Risk Analysis

Food inspection in the GCC states, among which is Saudi Arabia, is carried out by official bodies. However, most of the public health inspectors suffer from poor training and qualifications at the level of the Gulf countries, including Saudi Arabia. Although Saudi Arabia applies GMP and HACCP preventive measures. However, the number of public health inspectors appointed for this purpose is very limited. Due to the country's great dependence on importing foodstuffs from various countries. Therefore, there is an urgent need to provide inspectors with current knowledge and education through specialized training courses, especially in HACCP implementation. In terms of reducing the risk of foodborne pathogens to an acceptable level, preventive measures are required at all stages of the food production chain, not just through food inspection and final product analysis. Therefore, the application of preventive measures such as GAP, GMP, and Global Health Practices, with the application of HACCP, is very important to achieve acceptable levels of food safety(FAO 2014).

### 11.3.2 Lack of Academic Programs for Food Safety

In fact, only a few Saudi universities have faculties of food science, agriculture, and veterinary medicine. Also, educational programs in these colleges have a limited focus on food safety. In addition to the lack of specialists in this aspect, and there are no national educational programs in Saudi Arabia that focus on improving knowledge and practices related to food safety. Therefore, launching specialized food safety programs in Saudi academic institutions is essential to improve the food safety system and build its capacity (Al-Subaie and Berekaa 2020).

### 11.3.3 Lack of Coordination in Performing Tasks Between Different Agencies

Although the Food and Drug General Authority is the main organization responsible for managing food control in of Saudi Arabia, the Saudi Standards and Metrology Authority plays a major role in establishing, amending and updating the policies and procedures of the food control department at the central and local levels, there is often duplication and overlapping of task, and a lack of coordination among organizations. Lack of coordination in tasks and duties reduces the efficiency and effectiveness of food safety systems and regulatory authorities (Idriss and El-Habbab 2014; Owusu-Apenten and Vieira 2013).

### 11.3.4 Challenges of Controlling Imported Food

The food industry in Saudi Arabia confronts numerous obstacles in its market. The primary cause of the country's vulnerability is the scarcity of local agricultural production due to the exceedingly arid climate, which presents a significant hurdle for the domestic food industry. Therefore, food processing companies heavily rely on foreign food products and imported raw materials. To reinforce national governance of food safety, the local government has commenced a process of consolidating all food control and regulatory activities under a single authority of experts, known as the SFDA. However, this process remains incomplete and requires further refinement. The food control system is still fragmented among various agencies, resulting in ongoing issues especially at the border. Throughout the supply chain, numerous public organizations bear shared responsibilities. It is imperative for Saudi Arabia to shift from a multi-agency approach to a unified agency approach, not only to alleviate administrative complexity but also to ensure a reliably secure national food supply that adheres to both local and international food regulations as well as the Halal religious standards. To guarantee the safety and quality of imported food, it is crucial to implement effective border controls. Securing trade agreements with global governments and food organizations and conducting official visits to importing countries are essential measures in ensuring national food security and mitigating the risks of food safety hazards and fraudulent activities before imported products reach the border (Al-Subaie and Berekaa 2020).

## *11.4 Food Labeling Requirements*

The objective of food labeling is to furnish consumers with accurate and pertinent details regarding the products they consume. By displaying information such as nutritional facts, handling instructions, suggested storage temperatures, and a list of ingredients, food labeling enables consumers to compare and contrast different products and make informed choices about their dietary intake. This information can assist consumers in selecting foods that align with their dietary preferences and requirements; and identifies the company responsible for the product. This is in addition to the name and address of the responsible company. Whereas, in the event of a defect in the product, the company is summoned and communicated with it and allegations of nutritional content, in addition to the nutritional value of the product and its content of tonics and fortified materials, if any, are voluntary information.

Food labeling requirements are established by various laws, including the "Fair Packaging Act (FPLA) of 1967, the Federal Food, Drug, and Cosmetic Act (FD&C), the Nutrition Labeling Education Act of 1990 (NLEA), the Dietary Supplement Health and Education Act of 1994 (DSHEA), the Food Allergen Labeling and Consumer Protection Act of 2004 (FALCPA), and the Patient Protection and Affordable Care Act of 2010". These laws mandate the information that must be displayed on food labels to ensure that consumers have access to accurate and useful information about the products they purchase. By following these labeling requirements, food manufacturers can provide transparency and clarity regarding the contents, nutritional value, and potential allergens of their products. This information empowers consumers to make informed decisions about the foods they consume and can promote better health outcomes. In general, if a product must comply with standards set by the Saudi Standards, Metrology and Quality Organization (SASO), labeling requirements must comply with SASO requirements. If the product does not have a SASO standard but does have a relevant regional or international standard (e.g. IEC, ISO, GSO, EN, ASTM), the labeling requirements must comply with the requirements of the applicable standard (Owusu-Apenten and Vieira 2013).

## 12 Impact of Climate Change on Food Safety and Quality

Food security is often equated with having enough food, but this perspective oversimplifies the matter. Food security involves not only having access to sufficient food, but also to food that is safe and nutritious. As a result, food safety is a crucial component of food security. Various factors, such as global trade, technological and socio-economic progress, urbanization, and agricultural land use, can impact food safety. Climate change and variability are among these factors, and they can alter the occurrence and nature of food safety hazards. Climate change has the potential to create various hazards throughout the food chain, starting from primary production and continuing until consumption. It can lead to both direct and indirect effects on the emergence of these hazards. The primary culprit behind climate change is the discharge of greenhouse gases (GHGs), which can influence factors such as temperature, relative humidity, precipitation, and ultraviolet (UV) radiation, ultimately resulting in climate variability (Ariño 2015; Wu et al. 2016).

According to the International Panel on Climate Change and numerous authors, global climate models have projected that average global warming may range from 1.5 to 5.8 °C, and there could be a rise in mean global precipitation by 5 to 15% by the conclusion of this century. These alterations in climate-related factors can have a significant impact on food safety. Warmer temperatures, shifts in precipitation patterns, modifications in the water cycle, and more frequent and severe extreme weather events, such as heat waves, droughts, and floods, are among the consequences. The increasing temperatures can also have far-reaching effects, such as the melting of ice caps, ocean warming and acidification, rising sea levels, increased erosion, and modifications in deep ocean circulation (Duchenne-Moutien and Neetoo 2021).

Climate changes pose a threat to the food supply chain such as the exacerbation of food borne diseases and the risk of chemical agents such as mycotoxins, pesticides and heavy metals. Climate change can also lead to a shortage of safe water for irrigation of agricultural products, increased use of pesticides, difficulty in controlling temperature, flash floods, and the flow of chemical pollutants into natural water cycles. These risks increase the potential for exacerbation of foodborne illnesses, poisoning, antibiotic resistance, and prolonged bioaccumulation of harmful substances in the human body. Therefore, actions must be taken to improve food safety and reduce risks related to climate changes (Duchenne-Moutien and Neetoo 2021). Climate change's effect on food safety will impede endeavors to secure food supplies in the face of a growing global population and escalating demand for food. An approximate 14% of food produced is lost during the production phase, before reaching the retail level or consumers (FAO 2022). This loss can be attributed to various food contamination issues (FAO 2017), and climate change can worsen food loss by creating conditions that facilitate the spread of foodborne hazards.

### *12.1 Effect of Climate Change on the Risk of Foodborne Illness*

Climate change can have significant impacts on the risk of foodborne illness, particularly through changes in the transmission of bacterial pathogens and the contamination of food with toxic substances. Rising temperatures and changes in precipitation patterns can create ideal conditions for the growth of harmful bacteria and other pathogens that cause foodborne illness. This includes Salmonella, E. coli, and Listeria, which can thrive in warm, moist environments.

Using unclean and unsafe water for handling and cleaning food poses a significant risk factor for foodborne illnesses. In low-income countries, water quality and quantity are particularly concerning, as it extends beyond the food chain. Water-related infections are among the leading causes of death and disease globally. Furthermore, it should be noted that climate change has worsened the challenges faced by the health sector in managing food and waterborne diseases, as mentioned by Cissé (2019).

The evidence is compelling that bacterial pathogens causing gastrointestinal infections have a direct positive correlation with ambient temperature. This is primarily due to higher temperatures facilitate faster replication of these pathogens. As a result of the warming trends observed in the United States, particularly in the southern states, there is a possibility of an increase in the incidence of Salmonella infections (Akil et al. 2014).

A study published in the journal Environmental Health Perspectives in 2019 found that climate change could lead to an increase in cases of Vibrio infections, which are caused by bacteria found in warm coastal waters and can be transmitted through contaminated seafood. The study modeled the impact of climate change on Vibrio populations in the North Atlantic and found that rising sea surface temperatures could lead to an increase in the number of cases of Vibrio infections. Vibrio bacteria are responsible for several diseases in humans, including cholera and gastroenteritis, and are known to thrive in warm, brackish waters. The results indicated that by 2100, many coastal regions around the world could experience a significant increase in the risk of Vibrio infections due to warming ocean temperatures. The study also found that some regions, particularly in Southeast Asia and the western Pacific, are at particularly high risk of Vibrio infections (Trinanes and Martinez-Urtaza 2021).

In 2018, it was found that climate change could increase the risk of leafy greens being contaminated with Escherichia coli, a common type of bacteria that can cause foodborne illness. It found that rising temperatures and changes in precipitation patterns could increase the risk of contamination through irrigation water and contaminated soil. The study used laboratory experiments to simulate the effect of different temperature and humidity conditions on the growth and survival of *E. coli* on spinach leaves. The researchers found that increased temperatures and humidity levels, which are expected to occur as a result of climate change, led to a significant increase in the growth of *E. coli* on spinach leaves. Specifically, the study found that at higher temperatures and humidity levels, *E. coli* bacteria grew more quickly and in higher concentrations on spinach leaves. Study highlights potential public health risks posed by climate change, noting that higher temperatures and humidity levels can increase the risk of foodborne illnesses caused by *E. coli* (Macarisin et al. 2013).

## 12.2 Changes in Precipitation Patterns and Flooding Could Increase the Uptake of Toxic Metals

The interplay between floods and droughts can significantly impact variations in soil redox potential (EH) and soil pH, which can, in turn, affect the solubility of redox-active elements such as Fe, Mn, and $SO_4^{2-}$, among others (Pan et al. 2014). A study conducted over a three-year period examined how biochar affected the availability and distribution of cadmium (Cd) and lead (Pb) across various soil fractions during wheat cultivation. The study discovered that the use of biochar resulted in a significant increase in crop yield and decreased concentrations of Cd and Pb in wheat grain in 2014. However, in the following two years, which experienced heavy rainfall, the bioavailable (exchangeable) concentrations of heavy metals and the uptake of Cd and Pb by plants were considerably higher. As a result, the effects of biochar were more inconsistent and had a generally lower impact on reducing the uptake of heavy metals. These results suggest that variations in soil pH and redox, prompted by intermittent cycles of drought and flooding, exert a significant influence on the movement of metals by mobilizing and immobilizing metals that are linked with distinct mineral phases (Sui et al. 2018).

## 12.3 Algal Toxin

During their flowering phase, certain types of algae like dinoflagellates and diatoms can generate harmful substances. These harmful substances can gather in filter-feeding fish species and shellfish, potentially causing food poisoning in humans and posing a significant risk to their well-being. Algal toxins can cause a variety of diseases, including ciguatera fish poisoning (CFP), paralytic shellfish poisoning (PSP), amnesiac shellfish poisoning (ASP) and other different types of poisoning. In recent times, there has been a worldwide increase in harmful algal blooms, which is connected to eutrophication (an increase in nutrient concentration) in water bodies, the transportation of harmful algae species by ships' ballast water, and climate change (Marques et al. 2010).

The escalation in frequency, duration, and geographical spread of algal blooms is a result of rising temperatures, and this predicament is anticipated to exacerbate in the future due to projected warming. A recent investigation scrutinized climate change predictions for the period between 2030 and 2050, revealing that there is expected to be a surge in the frequency of harmful algal blooms of *Dinophysis* spp.

However, the ramifications of shellfish contamination with diarrhetic shellfish toxins remain ambiguous (van der Fels-Klerx et al. 2012).

## *12.4 Increased Mycotoxin Contamination*

Mycotoxins refer to harmful substances generated by fungi that can pollute food crops and endanger human health. The peril of mycotoxin contamination can be intensified by climate change, which can contribute to the creation of conditions that facilitate the growth of fungal pathogens.

Environmental changes have a gradual effect on plant growth and fungal diseases. The primary factor that affects the life cycle of fungi in an agroecosystem is the climate. The ability of fungi to colonize agricultural crops is affected by the climate, as it enables them to generate toxins and survive. Thus, climate affects the balance between plant growth and fungal diseases. Toxin-producing fungi can adapt to climate changes by altering their geographical distribution and the occurrence of mycotoxins. Climate change creates unfavorable conditions for crop growth globally, leading to the loss of arable agricultural areas and an increase in mycotoxins. For instance, global warming reduces the areas that are suitable for crop cultivation, making plants more vulnerable to fungal contamination. Moreover, the rise in temperature will favor heat-tolerant species, leading to an overabundance of Aspergillus over Penicillium species (Zingales et al. 2022). Under normal conditions, developing crops become highly resistant to infection by *A. flavus* and subsequent AFs contamination unless the environmental conditions favor fungal growth and crop susceptibility. However, according to Battilani et al.(2016) *A. flavus* could become a food safety concern in maize in central/southern Spain, South Italy, Greece, north/southeast Portugal, Bulgaria, Albania, Cyprus, and Turkey within the next century if temperatures increase by $+ 2$ to $+ 5$°C. *Paterson and Lima* also predicted that *A. flavus* may pose a greater risk than ochratoxin A (OTA) over the next 100 years, potentially outcompeting *A. carbonarius*. Moreover, García-Cela et al. (2014) suggested that in hotter climatic scenarios, *A. niger* could become more prevalent than *A. carbonarius* due to the former's greater adaptability to high temperatures and drier conditions (Giorni et al. 2007).

## *12.5 Reduced Nutrient Content*

Changes in rainfall patterns and higher temperatures can also affect the nutritional content of crops, reducing their quality and potentially leading to nutrient deficiencies in populations who rely on them as a primary food source. Climate change has the potential to impact human health in various ways, one of which is by altering the nutritional composition of crops. The productivity of plants is mostly linked to atmospheric carbon dioxide levels, which affects photosynthesis. Therefore, changes in atmospheric carbon dioxide concentration can have a ripple effect on the overall and micronutrient content of crops. If these changes result in a decrease in the essential nutrients found in staple crops, it could have severe repercussions for people living in areas where these crops are a primary source of vital nutrients. This is especially concerning given that nutrient deficiencies are already a significant public health issue globally (Dietterich et al. 2015).

## *12.6 Changes in Food Production and Distribution*

Climate change will have an impact on food production as it will respond to different climatic conditions within changing ecosystems. This will alter agricultural conditions and increase the need for adaptation. The food sector is responsible for contributing 15–30% of global greenhouse gas emissions through its various processes, including food production, processing, transportation, storage, preparation, consumption, and disposal. Most of these emissions stem from agriculture (45%), food processing (12%), and transportation (12%). There are initiatives available to reduce greenhouse gas emissions, such as introducing high-sugar grasses into livestock feed to lower methane emissions, or changing the timing of animal manure spreading to reduce nitrous oxide (Garnett 2008). However, such changes may negatively impact food quality and safety.

Changes in the climate can impact the safety of food throughout its journey from the farm to the consumer, with warmer temperatures potentially leading to the proliferation of harmful bacteria like salmonella (Lake et al. 2009). The relationship between crops and fungi can also be influenced by weather and soil conditions, resulting in the production of mycotoxins. Studies have shown that regions with higher temperatures in temperate Europe and the United States may experience an increase in mycotoxin problems due to the optimal conditions for mycotoxin production, while in countries like Australia, elevated temperatures may reduce fungal growth and mycotoxin production (Paterson and Lima 2010).

Rising ambient temperatures will influence all stages of the food cold chain, from the initial refrigeration or freezing of food to its transportation, storage, and display in retail outlets. Higher storage temperatures, in combination with increasing ambient temperatures, will result in greater human exposure to food that may be unsafe for consumption (James and James 2010). As temperatures continue to rise, changes are needed in the cold chain system, but implementing such changes often requires food refrigeration systems to consume more energy. Research has demonstrated that when ambient temperatures increase from 17 to 25 °C, the average power consumption of food refrigeration systems in small catering establishments increases by approximately 11% (James and James 2010). The generation of energy contributes significantly to the emission of $CO_2$. Studies in Australia have shown that the energy consumption involved in maintaining an uninterrupted food supply chain from farm to fork amounts to 19,292 GW hours per year, which is equivalent to 18 million tons of carbon dioxide emissions (Estrada-Flores and Platt 2007). Cold storage systems play a crucial role in reducing food losses and enhancing food security. However, upgrading existing cold storage facilities or constructing new ones, particularly in developing countries, can pose financial challenges, especially under changing climatic conditions. Moreover, extreme weather events, such as power outages, can increase the risk of food spoilage and storage facilities contamination in both homes and supermarkets. Additionally, melting permafrost in Arctic regions has led to the failure of traditional ice cellars, which may result in increased foodborne illnesses due to spoilage during storage (Yoder 2018).

## *12.7 Climate Change and Food Safety and Quality in Saudi Arabia*

Saudi Arabia has a significant surplus in its budget, thanks to its vast oil reserves, and its primary industry is the production and export of total petroleum liquids, which generates about 90% of the state's revenues (Rahman and Khondaker 2012).While the country's ability to import food commodities has allowed it to maintain food security, it is not entirely immune to food security threats. In context of agriculture and water resources, Saudi Arabia is among the poorest nations, with only 5% of its land being arable due to the harsh desert climate (Baig et al. 2012). This makes it highly susceptible to the adverse impacts of climate change (Rahman and Khondaker 2012). A recent study examined temperature and rainfall trends in Saudi Arabia over a 50-year period from 1967 to 2016. The study revealed a notable increase in the average temperature of 1.9 °C over the past five decades, with the highest rise recorded during the summer months, consistent with global trends. While rainfall had a positive effect on crop production, it was insufficient to counteract the negative impacts of escalating temperatures (Haque and Khan 2020).

Saudi Arabia is recognized as one of the world's driest and hottest countries, with the northern region experiencing rising temperatures during both daytime and nighttime over the past few decades, with an overall warmer climate throughout the Kingdom (Almazroui et al. 2017). The demand for food safety has grown due to changing consumer preferences influenced by higher living standards and increased concerns about food safety (Ortega and Tschirley 2017). Extreme weather conditions, as noted by *Mafie*, can hinder agricultural growth, and rising temperatures, along with increased moisture and $CO_2$ levels, can encourage the growth of weeds, pests, and fungi. The burgeoning population in urban and suburban regions of Saudi Arabia places strain on the country's natural resources and heightens the risk of $CO_2$ emissions (Mafie 2021). Hamieh et al. (2022) estimated $CO_2$ emissions from various sectors using default emission factors. The total emission was found to be 559 mty, and by including the Jazan refinery that started operations in 2021, the emission rise to 566 mty.

Climate Change (IPCC) report highlights that climate change is a pressing issue for communities worldwide, with increasing global warming and unforeseen climate changes posing immediate and long-term risks to the environment and human well-being. Environmental anomalies are primarily caused by heavy fuel consumption, urban sprawl, land use changes, and deforestation. The UN reports that billions of people worldwide are affected by these climate change manifestations. Saudi Arabia, with its dry climate, limited water resources, and vulnerable agriculture, has been experiencing the impacts of climate change for at least a decade, affecting both urban and rural dwellers. According to the 2007 Intergovernmental Panel on Climate Change report, climate change has resulted in global changes in precipitation patterns, and in Saudi Arabia, this has translated to increased rainfall. However, in major cities with unplanned settlements, this increased rainfall has led to hazards such as flash flooding.

Saudi Arabia has acknowledged the challenges posed by climate change and has implemented comprehensive programs and institutional arrangements at the national level to address them. The country's national vision for 2030 aims to reduce its reliance on oil and create a more environmentally focused economy by investing in clean energy projects, including solar energy. Saudi Arabia is committed to reducing its annual carbon emissions by up to 130 million tons by 2030. The country has also collaborated with international stakeholders and endorsed the Paris Agreement in 2016 as part of its efforts to combat climate change and its effects (Saghir 2021).

While Saudi Arabia may encounter challenges related to food safety due to the impact of climate change, the country is adopting a proactive approach to address this issue. This could be attributed to the country's recognition of the potential severe consequences of climate variability. The Kingdom is aware that any global shocks to agriculture caused by climate change or geopolitical instability could worsen the situation, posing a threat to both food security and nutrition in the country (Haque and Khan 2020).

## 13 Conclusion and Prospects

In conclusion, climate change has a significant effect to the safety and quality of our food supply. The rising temperatures, extreme weather conditions, and changing precipitation patterns are affecting food production, distribution, and storage, leading to an increased risk of foodborne illnesses and contamination. Climate change effects on food safety are complex and far-reaching, requiring a multidisciplinary approach to tackle them effectively. Collaboration among experts from different fields is essential to better understand the risks and develop mitigation strategies. Addressing the effects of climate change on food safety and quality is crucial for ensuring the health and well-being of people worldwide and securing a sustainable food supply for future generations.

Finally, ensuring food safety and quality is a crucial issue in Saudi Arabia, given its reliance on food imports and limited arable land due to its harsh desert climate. The country is vulnerable to the effects of climate change, which can impact the availability and safety of food. However, the government has taken steps to address these challenges, including implementing strict food safety regulations, investing in agriculture and water resource management, and promoting sustainable food production. Collaboration between various stakeholders, including government agencies, food producers, and consumers, is necessary to ensure a safe and sustainable food supply in Saudi Arabia. Continued efforts to improve food safety and quality will be essential for the health and well-being of the population and the country's sustainable development.

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# Chapter 20
# Role and Contributions of Nutrition Security Institutions in Saudi Arabia

**Muneera Q. Al-Mssallem and Randah M. Al-Qurashi**

**Abstract** Nutrition security is an essential issue of life for residents worldwide. Nutrition security institutions play a vital and effective role in ensuring the health and safety of country populations. This chapter highlights the roles of these various institutions and organizations and their contributions to nutrition security in the Saudi Arabia (KSA). In KSA local production is insufficient to meet domestic requirements. Some strategies have been suggested to overcome this dilemma by creating opportunities to build a sustainable agricultural sector and promoting national crops, such as date palms, which are best suited to the KSA's climate conditions. In fact, Saudi Vision 2030 focuses on achieving environmental sustainability and contributing to enhancing sustainable food and nutrition security. The Saudi Food Security Strategy initiative was introduced by the Ministry of Environment, Water and Agriculture (MEWA). The main objectives of the MEWA are to ensure the availability and sustainability of strategic commodities by enhancing a permanent food production system for various differential commodities and increasing the diversity in external food sources. The MEWA includes the Saudi Grains Organization and National Centre for Palms and Dates, which both play a major role in food and nutrition security in the KSA. Additionally, the Ministry of Health (MoH) contributes very well to nutrition security through its major mission, including leading the KSA's nutrition program. Other examples of selected institutions and organizations that contribute very well to nutrition security are universities, the Saudi Food and Drug Authority, and the Saudi Chambers of Commerce and Industry.

**Keywords** Environmental sustainability · Ministries · Nutrients · Nutrition security · Universities

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M. Q. Al-Mssallem (✉) · R. M. Al-Qurashi
Department of Food and Nutritional Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia
e-mail: mmssallem@kfu.edu.sa

R. M. Al-Qurashi
e-mail: ralqurashi@kfu.edu.sa



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# 1 Introduction

The Saudi Arabia (KSA) has based its Vision 2030 on building a sustainable agricultural sector for achieving food and nutrition security. The wise leaders of the Kingdom are keen to support the various sectors to achieve this vision by enhancing environmental sustainability and contributing to sustainable food and nutrition security. The Kingdom has exerted all its efforts in striving towards food security, ensuring access to safe and nutritious food locally, and cultivating healthy and balanced eating habits among populations, considering the importance of food and nutrition security. As nutrition security is a fundamental pillar for a healthy life and a crucial element for public health, there are several institutions and organizations in the KSA concerned with nutrition security. Among these institutions is the Ministry of Environment, Water and Agriculture (MEWA). In fact, the MEWA has adopted the Saudi Food Security Strategy initiative (MEWA 2018).

Another important governmental institute in the KSA is the Ministry of Health (MoH). One of its essential missions is the promotion of general health and prevention of diseases. Indeed, the MoH exerts its role in promoting nutrition awareness among patients through inaugurating nutrition clinics in several regions of the Kingdom (MoH 2016). Additionally, the KSA's nutrition program was assigned to be led by MoH (MEWA 2018).

There is a strong relationship between nutrition security and human health that can be achieved through a healthy diet and a healthy lifestyle, including physical activity and adequate nutrient intake (Ayala and Meier 2017). A recent report (2020) from the Saudi Food and Drug Authority (SFDA) showed that the food system in the KSA is dependent on trade to supply food intermodality where approximately 80% of food is imported, including meat, dairy products, cereals, fruits and vegetables. Factors such as climate change, water scarcity, decline of environmental resources, limited cultivable lands, and population growth pose threats to nutrition security in the KSA (Abubakar and Dano 2020). Nevertheless, there are vigorous efforts to overcome these obstacles, create opportunities to build a sustainable agricultural sector, and increase citizens' awareness of their nutritional requirements to achieve nutrition security. This chapter focuses on the roles of institutions and organizations and their contributions to achieving nutrition security in Saudi Arabia.

## 2 Nutrition Security

### *2.1 Definition*

Nutrition security is a tool for measuring food consumption to determine whether a nation's food supply is sufficient in quantity and quality to meet the dietary requirements of all people of all age groups (FAO 2010). This definition of nutrition security is embedded within the basic components of food security, which include food availability, accessibility, utilization, and stability (Jarosz 2011).

In the KSA, local production is insufficient to meet domestic requirements due to limited cultivable lands and water scarcity (Fiaz et al. 2018; Baig et al. 2019). In addition, the KSA may have one of the highest rates of wasted food globally (Baig et al. 2019). Therefore, some strategies have been suggested to overcome this dilemma by promoting national crops, such as date palms, which are best suited to arid and semiarid climate conditions (Tengberg 2012). Dates are of great production in the KSA and can help achieve food security (Fiaz et al. 2018). More details regarding the nutritional security of this product are mentioned in Sect. 3.1.1.

### *2.2 Development of the Nutrition Security Concept*

Since its introduction three decades ago, the concept of nutrition security, which is an elemental component of food security, has significantly evolved (Hwalla et al. 2016). It is well-documented that food security first originated in the mid-seventies, and it was revised several times (Heidhues et al. 2004; FAO 2006). An acceptable definition of food security became available, and from that revised version, nutrition security was derived (Jacobs 2009). In fact, nutrition security should be embedded within the dimensions of food security (Pingali et al. 2005).

From this angle, it is clear that the concepts of food and nutrition security are closely interrelated to each other, as nutrition security simultaneously requires food and health care. Therefore, achieving nutrition security will mainly lead to food security.

### *2.3 Determinants of the Nutrition Security*

Nutrition security has three determinants: accessibility of adequate food, diet practices, and health care. These determinants firmly overlap with the dimensions of food security. Thus, there are close linkages between food security and nutrition security (Pieters and Swinnen 2016).

### 2.4 *Measurement of the Nutrition Security*

Nutrition security can be assessed through nutritional status, food/fluid intake, food utilization, health status, food accessibility and dieting, and health and sanitation. Certainly, some of these assessments can be applied to food security (Hwalla et al. 2016; Zurek et al. 2018).

For a healthy and active life, all medical and health care services mainly support nutrition security. At this stage, it is evident that nutrition security plays a crucial role in managing certain communicable and noncommunicable diseases (Demeke and Kariuki 2020; Seligman and Berkowitz 2019). In fact, most nutrition security studies focus on the relationship between nutrition and health. The impact of nutrition on health is a crucial issue and most intense efforts are centred on securing sufficient and healthy food and educating populations at household and individual levels to protect them from chronic and fatal infectious diseases resulting from malnutrition or overnutrition (Brown et al. 2020; Gundersen and Ziliak 2015; Seligman et al. 2010).

## 3 The Role and Contributions of Nutrition Security Institutions in Saudi Arabia

A number of institutions in the KSA have contributed to nutrition security and are working together with the government to achieve this goal throughout the Kingdom, including ministries, universities, research centres, and governmental and nongovernmental organizations. More details about these institutions and their roles in nutrition security are discussed below.

### 3.1 *Ministry of Environment, Water and Agriculture and Its Role in Nutrition Security*

The Ministry of Environment, Water and Agriculture (MEWA) has prioritized achieving food security by accomplishing water security, contributing to achieving sustainable food security and providing high-quality sustainable services and agricultural products. MEWA has started a strategic plan linked to the King Abdullah Initiative for Food Security. This strategy provides a detailed presentation for the food security system in the KSA based on five strategic objectives. These objectives have been translated into 11 strategic programs (Fig. 1), including the KSA's nutrition program (MEWA 2018).

The Saudi food security initiative includes, preparing a comprehensive food security and nutrition strategy; designing and establishing an effective strategic food reserve and storage program; establishing an early warning system for food security

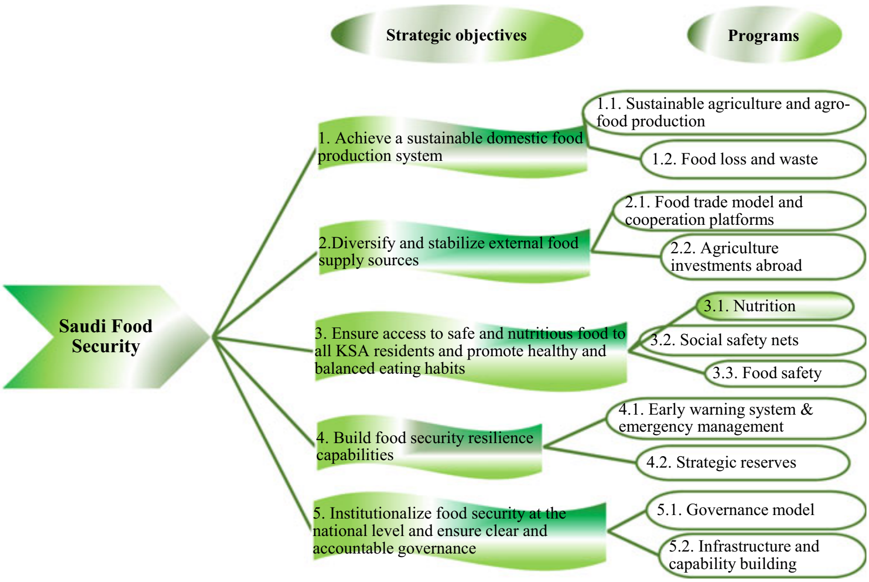


**Fig. 1** The five strategic objectives and the eleven programs of Saudi food security initiative. Figure is prepared by M. Q. Al-Mssallem

that includes the market information system; building a national program to reduce food waste and loss based on international standards and experiences; preparing an effective policy for food trade and imports; carrying out an awareness training program to enhance the knowledge, skills, and competencies of national resources in various aspects of food and nutrition security; preparing a strategy to encourage agricultural investment abroad, including incentives for Saudi companies and businessmen to invest in agricultural activities abroad; and the Kingdom's participation in regional and global committees, agreements, and treaties to enhance food security (MEWA 2018).

The KSA's nutrition program (Fig. 1, Sect. 3.1) aims to improve the dietary habits of Saudi residents by increasing milk, fish, and fruit consumption and decreasing sugar and saturated fat consumption (Fig. 2). This program has been assigned to be led by the MoH. More details in this part are mentioned in Sect. 3.2.

It is well known that the MEWA has the so-called Sister Entities including the General Food Security Authority (GFSA) and National Centre for Palms and Dates. Both of these entities play a major role in food and nutrition security (MEWA 2020). More details on the roles of both entities are mentioned in separate subsections below.


**Fig. 2** The Saudi Arabia' Nutrition program and its objectives, functions, and key performance indicators. Figure is prepared by M. Q. Al-Mssallem

### 3.1.1 The Role of National Centre for Palms and Dates in Nutrition Security

The National Centre for Palms and Dates (NCPD) contributes very well to developing the date sector in Saudi Arabia mainly by producing dates with good quality and efficiency. The role of the NCPD is focusing mainly on raising the value of the Saudi's exports of dates, improving the quality of the dates sector in Saudi Arabia, and increasing the local consumption of dates (NCPD 2023).

In fact, date palm occupies a great position among the Arab population, especially Saudis, in terms of their habitual eating patterns. It is well known that date palm trees are adapted to grow in arid and semiarid regions, such as the Arab Peninsula (Tengberg 2012). Saudi Arabia is characterized by a harsh environment that is suitable for cultivating date palm trees with more than 28 million date palm trees producing over 1.2 million metric tons (mt) annually. It has been reported that local sufficiency of dates is achieved, and Saudi dates and date products are now exported worldwide to several countries (General Authority for Statistics 2015).

Some works have been published on date palm fruits and their role as an important fruit in securing nutrients and protecting the human body from various chronic degenerative diseases (Al-Mssallem 2018a, 2020). A recent study revealed that consuming approximately 7–9 date palm fruits could secure approximately 11% and 16% of the daily recommended dietary allowances (RDA) of energy and simple carbohydrates, respectively. Moreover, the consumption of date palm fruits has resulted in the intake of approximately 25% of the recommended daily requirement of potassium and above 20% of the requirement of both fibre and magnesium (Al-Mssallem et al. 2019). This finding highlights the important role of date palm fruits as an essential element of food and nutrition security in the past, present and future among the Saudi population.

#### 3.1.2 The Role of General Food Security Authority in Nutrition Security

The Saudi Grains Organization (SAGO) was established by the Royal Decree issued in February 1972 and its name was transformed into General Food Security Authority (GFSA) in January 2023. It is considered one of the leading national institutions in the KSA. It is clear that the vision of GFSA is to lead food security efforts and ensure the availability and sustainability of strategic stocks. In fact, one of the priorities of GFSA is to support the development of food commodities sector related to strategic stocks. Additionally, this authority supervises the safety and quality of wheat and its products. In fact, the consumption of wheat grains and their products comes second after rice consumption among Saudis (MEWA 2020). Grains and grain products play an essential role in food and nutrition security, as they are considered an important source of energy in the form of carbohydrates. In addition, they are a good source for protein, fibre, and a range of micronutrients, such as B complex and magnesium. Grains and grain products also exert potential health benefits due to their content of bioactive compounds (McKevith 2004). Therefore, securing wheat and its products and maintaining their quality can contribute to securing the nutrients necessary for human health. Indeed, this is what GFSA is keen on and places it among its major priorities to achieve its primary goals based on its vision and mission (SAGO 2023).

Recently, GFSA launched a national initiative to reduce food waste and loss in Saudi Arabia. This initiative will be implemented in five stages by following the international standards of food waste and loss. Moreover, GFSA has established the first and largest regional grain station in Yanbu Commercial Port to sustain food and nutrition security (MEWA 2020).

### *3.2 Ministry of Health and Its Role in Nutrition Security*

Since its establishment in 1951, the Ministry of Health (MoH) remains the first entity responsible for providing curative and preventive health care services to more than 35 million citizens and residents, in addition to providing services to approximately 20 million visitors annually during the Hajj and Umrah periods. The MoH has made great and qualitative achievements in ensuring the provision of health care, providing the best health services at all levels, promoting public health and preventing diseases. The MoH has sought within its strategic objectives to enhance preventive and curative care and to make the most of the available resources (MoH 2020).

In fact, the MoH is the main leader of the KSA's nutrition program. The nutrition program consists of six major initiatives (Table 1), and its implementation is monitored by several key performance indicators. These indicators include the prevalence of diabetes and obesity in the KSA, actual consumption of commodities, and the ratio of schools and restaurants abiding by nutrition program (MEWA 2018).

The MoH is making all possible efforts to lay the foundations for health services and provide them for every beneficiary (Figs. 3 and 4), through various health facilities, as well as fruitful and constructive cooperation with other government health sectors and private sector facilities. Figures 3 and 4 present some of health indicators which reflect progress and development in the health sector in the Kingdom (MoH 2021).

**Table 1** The Saudi Arabia's nutrition program initiatives and activities

| | Initiatives | Activities |
|---|---|---|
| KSA's nutrition program | 1. Validate KSA nutrition habits | 1.1. Validate dietary consumption targets for KSA population |
| | 2. Set KSA nutrition program regulatory framework | 2.1. Set up and roll-out adequate regulations to ensure private sector adherence to the government's targets |
| | | 2.2. Design incentives structure to ensure private sector collaboration in the provision of nutritious food for the kingdom |
| | 3. Educate students on the importance of adopting a healthy diet | 3.1. Include nutrition education in school curriculums |
| | | 3.2. Provide nutritious counselling in school to promote adoption of a healthy diet and track student's health |
| | 4. Inform consumers on the benefits of eating nutritious food | 4.1. Launch national media campaign to raise awareness on the importance of adopting a healthy diet |
| | 5. Continuously monitor diet of KSA residents | 5.1. Monitor and enforce provision of nutritious food by private and public sector facilities |
| | | 5.2. Monitor prevalence of obesity and diabetes in the kingdom |
| | 6. Revise and refresh KSA nutrition and health targets | 6.1. Revise and refresh nutrition and health targets based on achieved progress |

*Source* MEWA (2018)

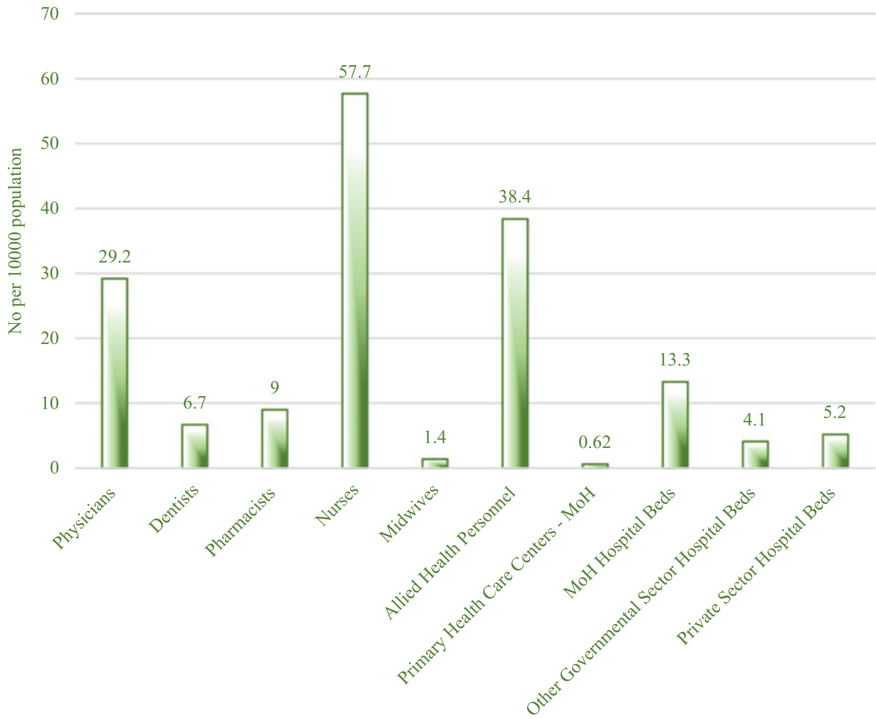


**Fig. 3** Health resources indicators per 10,000 population in 2021. *Source* MoH (2021)

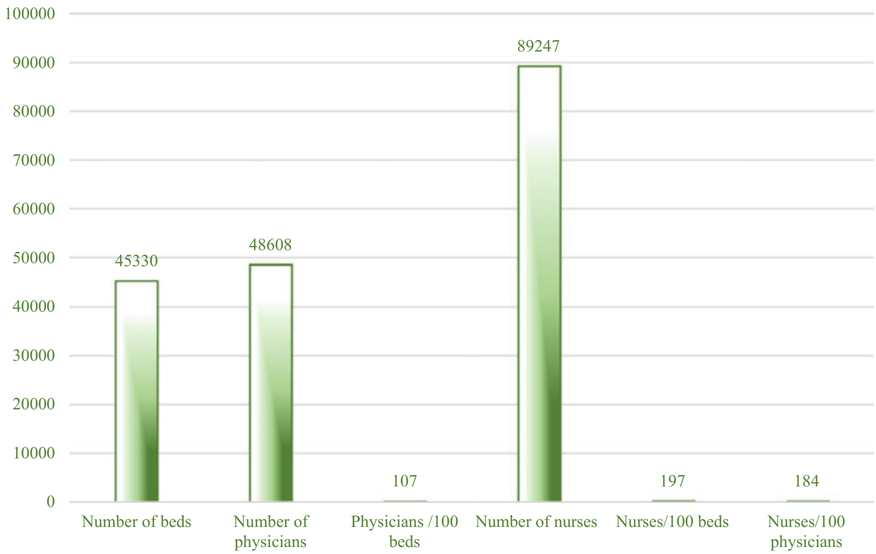


**Fig. 4** Selected indicators of available resources at Ministry of Health in 2021. *Source* MoH (2021)

## *3.3 Saudi Universities and Their Roles in Nutrition Security*

In Saudi Arabia, there are approximately 42 public and private universities (Al-Mssallem 2018b). Some of these universities, such as King Faisal University (KFU), have adopted the concept of Food Security and Environmental Sustainability as its identity. The role of universities in the KSA is to ensure that the wheels of food production, knowledge and skills, and challenges facing food insecurity are solved and therefore increase their contributions towards development technology. The university should identify research gaps that share knowledge and focus on food policy and safety and develop agricultural technology that can solve food and nutrition insecurity. More detail on this concern is discussed below for some selected Saudi universities.

### 3.3.1 King Faisal University (KFU)

The King Faisal University (KFU) was established in 1975, and it is one of the first seven universities established in the KSA. The role of KFU in nutrition security stems mainly from its identity, which is based on food security and environmental sustainability. In fact, KFU possesses basic elements for enhancing food security and environmental sustainability, such as the availability of knowledge and experience in the areas of food security and environmental sustainability. The university also has a prominent role in supporting scientific research related to food security and environmental sustainability and adopting several transformational initiatives to serve the purposes of food security and environmental sustainability, especially in the food and renewable energy industries. The university also plays a role in holding conferences, workshops and seminars that address topics related to food and nutrition security, such as the recent one titled "*The 1st International Conference in Food Security and Environmental Sustainabilit*y" (KFU 2022) and "*The Impact of COVID-19 on Global Food Security*" (KFU 2020a).

The identity of the KFU is related to Kingdom Vision 2030, which defines the achievement of development and food security as well as the sustainable use of water resources as part of its strategic goals. Moreover, the identity focuses on achieving food security, whereas food security sustainable agricultural production includes upgrading plant, animal, and fishery production both quantitatively and qualitatively to increase production, control pests, reduce losses in crop production, and using innovation and technology (KFU 2020b).

College of Agriculture and Food Sciences, prepared and presented a research chair on food security to KFU. The University has signed a contract with ALbilad Bank to sponsor the chair and then after it entitled Albilad Bank Chair (BBCFS) for Food Security in the KSA. BBCFS is a scientific chair focusing on food security issues that aimed to address the current and future food security challenges in KSA; achieve the identity of KFU and enhance its pioneering role in community engagement; to enrich scientific research; and to qualify the national cadre for achieving food security in accordance to the Kingdom's Vision 2030 (Ahmed 2023).

The chair's objectives include studying the most important current and future challenges related to food security in the KSA; identifying the determinants and constraints that hinder achieving food security in the KSA; conducting scientific research to determine and minimize food gap volume for strategic agricultural products in the KSA; providing consultancy services in the fields of food security and food waste and loss reduction; holding and organizing panel discussions, workshops, conferences and training courses that are relevant to food security issues; building and activating the cooperation with the local, regional and international institutions and agencies relevant food and food production for enhancing the exchange of expertise and experiences in the fields of food security; and contributing with funder (Albilad bank) in achieving its social responsibility via reducing food waste and loss and enhancing the optimal use of food products to achieve food security (Ahmed 2023).

The College of Agriculture and Food Sciences (CAFS) is one of the four colleges initiated by KFU (Al-Saadat et al. 2004; KFU 2005). This college contributes effectively to achieving food and nutrition security in the KSA, as it aims to play a crucial role in achieving the university's identity of food security and environmental sustainability by focusing its current research projects and future plans in the areas of food and nutrition security and environmental sustainability. CAFS actively contributes to the growth of the agricultural sector and increasing food production capacity, quality, and safety in the KSA and its neighbouring countries. The college possesses qualified human potential from faculty members and researchers, through whom the college can provide appropriate solutions to agricultural problems via conducting relevant applied scientific research, providing consultancy services to farmers and stakeholders, and contributing to enhancing the improvement of agricultural practices for the benefit of citizens and the country. In addition, the college contributes to graduating qualified cadres and conducting scientific research in the different agricultural disciplines among which those related to nutrition industries, food systems and their relationship to diseases, and public health and giving them priority in achieving the vision of KFU (Al-Mssallem 2018b). Moreover, CAFS has played a fundamental role in many achievements in the fields of food and health by establishing and activating joint cooperation with many organizations related to the food industry to achieve added value and provide healthy, safe foods for Saudi citizens that meet their age needs, tastes and food preferences (KFU 2020b).

### 3.3.2 King Saud University (KSU)

King Saud University (KSU) is one of the earliest established universities in the KSA. It is the first institute in higher education in Saudi Arabia that was opened in Riyadh in 1957 established with all its colleges, institutes, laboratories, and research centres. In 1958, three colleges were established: the College of Sciences, College of Business, College of Pharmacy, and the College of Agriculture (now known as the College of Food and Agriculture Sciences). Currently, there are approximately 24 colleges that include several disciplines (KSU 2020a).

King Saud University's mission is based on providing distinguished education and producing innovative creative research that serves society and contributes to building a knowledge economy. It focuses on education quality, scientific research, and entrepreneurship (KSU 2020a). The university includes several research centres and institutes, such as the 19 College Research Centres, Prince Sultan Research Centre for Environment and Water and Desert, and other research centers and programs and institutes. All these centers and institutes are established to support scientific research that may directly or indirectly serve food and nutrition security in all its agricultural, environmental, food, and health aspects (KSU 2020b).

The College of Food and Agriculture has a long history of food and nutrition. The college has several research chairs focused on food and nutrition security, including King Abdullah bin Abdulaziz Chair for food security, Sheikh Muhammad bin Hussein Al Amoudi chair for water research, Green Energy Chair, Palm and Dates Research Chair, Engineer Abdullah Bugshan Chair for Bee Research, Precision Agriculture Research Chair, Dates Technology and Manufacturing Research Chair, Vector Research Chair, and Saudi Group Chair for Research and Knowledge Marketing.

In general, the main objectives of these chairs are to (1) monitor food security issues, (2) assess the nutritional values of consumed food in the Kingdom, (3) contribute to the agricultural policy for ensuring water and food security, and (4) invest foreign agricultural sectors and their role in food security. Additionally, they aim to determine how international trade can achieve food security by conducting scientific research and workshops. Moreover, the King Abdullah bin Abdulaziz Chair for Food Security focuses on monitoring food security status, providing advice on scientific research, and maintaining the stability of foodstuffs throughout the year (KSU 2020a).

The College of Applied Medical Sciences at KSU has established the National Nutrition Policy Chair. It has a vision of "A malnutrition-free society" and a mission of establishing and continuously updating the National Nutrition Policy to enable the prevention of malnutrition and its related diseases, and promoting public health. The objectives of the chair include preparing national nutrition policies in collaboration with government and non-governmental bodies; establishing nutritional recommendations for all groups; examining internal and external food sources and studying the system by which food can be accessed by different social groups; studying food costs for individuals and families in all KSA regions; disseminating awareness about the importance of appropriate and safe nutrition for all age groups and the way to achieve it; promoting special nutrition programs for improving public health; and supporting studies by researchers and graduate students in the field of nutrition (CAPS 2016).

#### 3.3.3 Imam Mohammad Ibn Saud Islamic University (IMSIU)

The mission of Mohammad Ibn Saud Islamic University (IMSIU) is to provide quality and distinguished activities in learning, teaching and scientific research. The university possesses several support deanships, research and service centres, and scientific research chairs. Its strategic goals include developing, and creating a strong research culture and a distinct research environment for researchers, and increasing research cooperation (IMSIU 2020).

Research cooperation is one of the university's roles in promoting and achieving food and nutrition security. An example of this is the university's cooperation with the GFSA to implement a national field project aimed at measuring food waste and loss and ways to reduce it. Determining the quantities and percentages of food waste and loss is one of the most important foundations and data on which food security is based, as researches and studies indicate that the increase in food waste and loss, along with the scarcity of natural resources, has a negative impact on all aspects of food security. Accordingly, the KSA launched a national program to conserve and utilize its natural resources efficiently, which was implemented by the GFSA in cooperation with Imam Mohammad Ibn Saud Islamic University (MEWA 2020).

The project implementation process goes through several stages according to a specific timetable. These stages include preparing the legislative framework to reduce food waste and loss in the KSA, continuous monitoring of food waste and loss, providing training on best practices applied to reduce food waste and loss, and promoting food waste recycling and capacity building. The program seeks to develop policies to reduce waste and loss in major food groups, such as wheat, rice, dates, vegetables, fruits, and red and white meat (MEWA 2020).

### *3.4 Saudi Food and Drug Authority (SFDA)*

The Saudi Food and Drug Authority (SFDA) was established under the Council of Ministers' resolution in 2003. The SFDA is responsible for protecting the human health of all populations in the KSA by ensuring that food and nutrition security is effective as well as the safety of biological and chemical substances and electronic products. The vision of the SFDA is to lead international science-based regulators to protect and promote public health. Their mission is to protect the community through regulation and effective controls to ensure the safety and security of food, drugs, medical devices, cosmetics, pesticides, and feed. The SFDA has projects that assists in improving food and nutrition security by a cooperation strategy regarding the scoop of food security and establishing the Gulf Food Safety Centre, which is important to increase food safety and security in the region. The main role of the authority is to ensure and control safety, security, and effectiveness of food and drugs for humans and animals. In addition, the authority contributes towards conducting research and applied studies to identify health issues and determine their impact on public health through partnerships with some university research centres (SFDA 2020).

#### 3.4.1 National Nutrition Committee

The National Nutrition Committee was recently stabilized under the organizational structure of the SFDA to involve the nutrition and health situation in the KSA to achieve the quality of life program and Saudi Visions 2030. It is a scientific advisory committee that aims to improve the nutritional status of the Saudi population. This helps to build a healthy society by conducting a scientific study in food and nutrition and maintaining human health and planning recommendations and guidance for the population. Furthermore, it is concerned with the nutritional status throughout the life stages of all populations (SFDA 2020).

### *3.5 Saudi Chambers of Commerce and Industry*

Saudi Chambers play an effective role in contributing to the service of the community and the development of its economic and financial activities in the Kingdom. The Council of Saudi Chambers includes approximately 28 Chambers of Commerce and Industry distributed throughout the Kingdom. The role of the Chambers of Commerce and Industry in food and nutrition security is to plan research and studies related to trade and industry and to provide comprehensive research for all aspects of economic variables. It also touches the needs and constraints facing the different sectors through specialized committees, such as the Food Industries Committee, Agricultural Development Committee and other committees. They provide their services to support and promote individuals and companies to take advantage of investment opportunities in agriculture, food industries and health to enhance food and nutrition security (CSC 2020).

Among the supporting activities that are arranged and implemented by the Chambers of Commerce in the field of food and nutrition security is the recent symposium entitled "Our Food Security between Reality and Future" organized by the Riyadh Chamber of Commerce (CSC 2020).

### *3.6 International Agencies in Saudi Arabia*

Saudi Arabia has been involved as a partnership with important United Nations (UN) agencies such as the Food and Agriculture Organization (FAO). This partnership includes providing support and boosting food and nutrition security. Additionally, Saudi Arabia is considered an active member in the World Food Program (WFP) and in its executive council. Recently, it was announced that the Saudi Arabia won for the fourth time in the membership of the executive board of the WFP for the period from 2020 to 2023. The executive council consists of 36 countries in addition to the European Union, which is the supreme governing body for the program and is responsible for providing international government support for the program, directing its policies, and supervising its activities (WFP 2019).

Moreover, there is cooperation between King Salman Humanitarian Aid and Relief Centre (KSRelief) and US Agency for International Development (USAID) to alleviate the suffering of countries in need and develop humanitarian working mechanisms to ensure the delivery of aid to their beneficiaries. The Kingdom's relief and humanitarian efforts have been implemented by KSRelief in many countries since it was founded in 2015. There is a close partnership between FAO and KSrelief that focuses on supporting crises and increasing access to nutritious foods. For instance, the amount of Saudi assistance presented to Yemen since 2015 has reached $14.5 billion, more than $2 billion of which was donated through KSRelief (FAO 2020).

## 4 Conclusion and Prospects

Nutrition security is an integral constituent of food security. In Saudi Arabia, several institutions and organizations contribute very well on nutrition security, such as ministries, universities, Saudi Food and Drug Authority, the Saudi Chambers of Commerce and Industry, and International Agencies. In fact, Saudi Vision 2030 focused on building a sustainable agricultural sector, improving agricultural productivity, and enhancing research and innovation capabilities for achieving sustainable food and nutrition security. On the other hand, the Saudi Food Security strategy is considered the most important initiative for achieving Saudi Vision 2030. The Ministry of Environment, Water and Agriculture has adopted the Saudi Food Security Strategy initiative. This strategy requires good cooperation between all governmental and nongovernmental sectors to achieve environmental sustainability and enhance sustainable food and nutrition security. It is well known that local production in Saudi Arabia is insufficient to meet people's requirements due to limited cultivable lands and water scarcity. Moreover, KSA has the highest rates of wasted food globally. Some strategies have been suggested to overcome these threats by creating opportunities to build a sustainable agricultural sector, enhancing external investment in food production, and increasing citizens' awareness of their nutritional requirements for achieving food and nutrition security. It is evident that dates production is of great importance in the KSA and can help achieve food and nutrition security. More research and studies on investments in the production and manufacturing industries of local production, such as dates, are recommended.

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