

REVIEW

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A comprehensive review on challenges and choices of food waste in Saudi Arabia: exploring environmental and economic impacts

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Abstract

Food waste is a major issue that affects the environment, the economy, and society at large. Food waste management has become a crucial concern in the context of Saudi Arabia, a nation undergoing fast economic expansion and shifting consumer patterns. This thorough analysis looks at the options and problems related to food waste in Saudi Arabia, emphasizing the effects on the country's economy and ecology. The report starts by describing the extent of food waste in Saudi Arabia, using studies and statistics that are currently accessible to provide readers a clear picture of the problem's scope. The main causes of food waste in the nation are then identified, including dietary habits, supply chain inefficiencies, cultural norms, and a lack of infrastructure for food recovery and redistribution. It also looks into the financial effects, including what it costs for individuals, companies, and the government, as well as any possible profits from programs to recycle and reduce food waste. The report also looks at current programs and tactics used to combat food waste in Saudi Arabia, including public-private partnerships, regulatory interventions, awareness campaigns, and technology advancements. It assesses the efficacy of these activities and pinpoints any shortcomings or potential areas for development. This study concludes by highlighting the critical need for coordinated effort to eliminate food waste in Saudi Arabia and highlighting the significance of governmental support, infrastructure investment, multi-stakeholder engagement, and public awareness. Saudi Arabia can lessen its environmental impact, preserve resources, provide economic opportunities, and support international efforts for sustainable development by reducing food waste.

Keywords Waste, Management, Saudi Arabia, Sustainability, Culture

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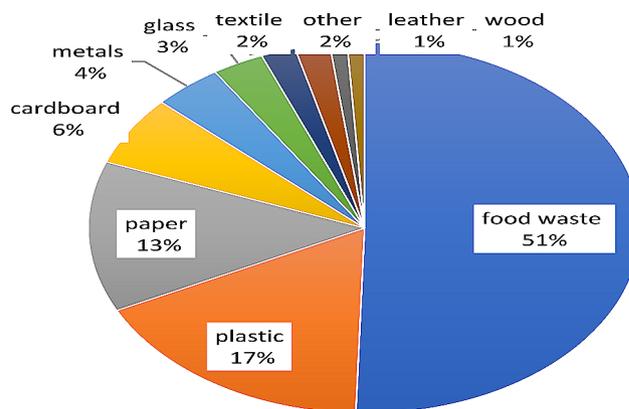
Table 1 Solid Waste production in different cities of Saudi Arabia [2]

Region /City	Population (millions)	Amount of waste (x 10 ³ tons per year)
Saudi Arabia	36.41	21,000
Major cities of KSA	14.12	9132
Riyadh	7.68	3310
Jeddah	4.7	2100
Makkah	1.58	1100
Madina	1.19	811
Al-Taif	1.01	670
Dammam	1.25	1210
Al-Hassa	0.70	790

Introduction

Stretching from the Arabian Gulf in the east to the Red Sea in the west, the Kingdom of Saudi Arabia (KSA) is strategically located in Southwest Asia at roughly 340 29' 55,040' E longitude and 16,022', 32,014 N latitude. With a population of 30.8 million according to World Bank data (WB, 2015), the Kingdom of Saudi Arabia has seen fast urbanization, industrialization, and population growth in recent decades, which has resulted in a notable increase in the generation of solid waste (Gajalakshmi et al. 2008). The average annual rate of population growth over the past forty years has been 3.4%, with urbanization rising from 50 to 80% of the total population between 1970 and the present. As a result, the production of uncontrolled solid waste has significantly increased (Ouda et al. 2013), with the majority of this trash being generated in the eight major cities of Saudi Arabia (Table 1). The Kingdom of Saudi Arabia generates 15.3 million tons of municipal solid waste (MSW) annually, or 1.4 kg per person per day on average (Nizami et al. 2015a). Garbage is usually disposed of by burning it in a landfill or by dumping it there. Some composting facilities have been set up to turn organic garbage into compost.

Nonetheless, there are serious environmental risks associated with these widely used garbage disposal techniques. Problems including bad odors, surface and groundwater pollution can result from improper waste treatment (Al-Sabahi et al. 2009). Furthermore, these waste management techniques rank second only to fossil fuels in terms of their large contribution to greenhouse gas (GHG) emissions (Rahman et al. 2012). About 40% of the garbage generated in the Kingdom of Saudi Arabia is made up of organic stuff. There are several places where this organic waste comes from, such as homes, canteens, hotels, and restaurants (Adhikari et al. 2008.). One affordable and environmentally responsible way to turn these organic wastes into useful products is by composting (Zhang et al. 2010). According to recent research (United Nations Development Program 2021),

**Fig. 1** Generation of solid waste in Saudi Arabia (UNDP 2021)

Saudi Arabia (SA) is one of the countries with the highest rates of food waste worldwide Fig. 1. Remarkably, food waste is the most common sort of garbage in Saudi Arabia (SA), accounting for at least half of the waste generated in the kingdom and more than any other category (United Nations Development Program 2021). Moreover, the quantity of food wasted here is more than three times that of food loss in Saudi Arabia (SAGO 2019). More than one-third of the food produced in the country is lost or squandered, according to a report by the Saudi Grains Organization (SAGO 2019).

According to the Food and Agriculture Organization (FAO), this percentage of food waste is marginally greater than the 31% global average (Food and Agriculture Organization of the United Nations FAO 2019). Individually, food waste in Saudi Arabia is more than twice as high as the global average, coming in at 250 kg as opposed to 115 kg. Furthermore, the average grain intake per person in Saudi Arabia is 158 kg, which is higher than the global average of 145 kg. During holidays like feast days and Ramadan, food waste increases dramatically (Baig et al. 2022). Furthermore, just the Holy City of Makkah produces 5000 tons of food waste in a matter of days during the Hajj pilgrimage (Ouda et al. 2017). The SA government will find it more difficult to reduce food waste at this event because, as noted by (The General Authority for Statistics 2019), local pilgrims made up 25% of the 2,489,406 pilgrims who participated in the 2019 pilgrimage season. Food security and the global economy are seriously threatened by the amount of food that is wasted or lost worldwide (Santeramo et al. 2021), which costs countries over USD 750 billion a year (FAO. 2015). The government of Saudi Arabia (SA) spends about SR 41.00 billion (about USD 11 billion) annually on food waste alone (SAGO 2019). 1.26 million people could be fed each year with the amount of food wasted (FAO. 2015). The sector wise generation food waste in Saudi Arabia is shown in Table 2.

Table 2 Food waste statistics by sector

Sector	Total Food Waste (%)	Key Challenges
Household	55%	Cultural practices, lack of awareness
Hospitality Industry	25%	Overproduction, plate waste
Retail Sector	15%	Excess inventory, imperfect produce
Food Processing	5%	Production inefficiencies

Furthermore, the landfilling of untreated food waste and the significant carbon footprint of 3.3 billion tons of CO₂ attributable to food waste overall make it a threat to the sustainability of the environment. 10% of the world's greenhouse gas emissions are caused by food loss and waste (UNEP 2022). The Saudi Green Initiative (SGI) was introduced in 2021 by the SA government, led by Crown Prince Mohammed bin Salman, as a response to these difficulties. By cutting carbon emissions, reaching net zero emissions by 2060, and protecting land and sea, this effort seeks to lead climate action in Saudi Arabia (The Saudi Green Initiative 2020). The SGI is in line with the Saudi Vision 2030; which places emphasis on the green economy and guarantees a sustainable and high-quality living for Saudi nationals and residents in Saudi Arabia (The Saudi Vision 2030). Additionally, the SGI supports multiple UN Sustainable Development targets (SDGs), such as targets 11, 12, and 13. It is clear that reaching these objectives and the Saudi Vision 2030 depend on minimizing food waste. Nevertheless, food waste continues to be a barrier to the SGI's advancement in spite of attempts. Due to its severe environment, which is marked by high temperatures, little rainfall, insufficient arable land, and restricted water supplies, Saudi Arabia confronts many obstacles in the growth of its agricultural sector (The Saudi Vision 2030). The demand for food among Saudis is also impacted by urbanization and improving living levels (Baig et al. 2017). As a result, with 80% of its food coming from imports, Saudi Arabia significantly depends on food imports to meet the requirements of its people (Baig et al. 2022). Despite government and research efforts to address the issue, it is shocking to see that over 30% of imported food is wasted (SAGO 2019), highlighting the need to understand the causes of this continued food loss, its effects, and practical management measures.

Research defines food waste as any edible substance that is thrown away before or after it expires and is acceptable for human consumption (Van Geffen et al. 2020). Conversely, food loss is the amount of food that is lost after harvesting but before it is ready for human consumption (Roodhuyzen et al. 2017). Food loss is defined by the FAO for the purposes of this study, which includes losses that occur from post-harvest through the

retail level but excludes losses beyond that (Food and Agriculture Organization of the United Nations FAO 2019). According to the UNEP, food waste happens in retail, food service, and consumer settings. Research has shown that, mostly as a result of consumer behavior, the percentage of food wasted is far larger than the percentage of food lost (Sobaih 2023). The management of food waste in Saudi Arabia (SA), specifically in food service enterprises, is the main emphasis of the current study.

Food waste has become a major global concern that affects social justice, economic viability, and environmental sustainability. The management of food waste poses opportunities and problems in the context of Saudi Arabia, a nation experiencing fast economic and social transition. This thorough analysis seeks to explore all facets of food waste in the Kingdom, including its effects on the environment, the economy, and the various approaches that can be used to lessen it. Food waste management is becoming more and more important as Saudi Arabia works to fulfill its Vision 2030 objectives, which include encouraging sustainable growth and minimizing its impact on the environment. This analysis examines how Saudi Arabia's food waste management is being shaped by contemporary methods, cultural influences, legal frameworks, and cutting-edge technologies. This review aims to provide policymakers, businesses, and communities with useful insights and recommendations for adopting efficient ways for decreasing, reusing, and repurposing food waste by offering a complete analysis of these issues. In the end, Saudi Arabia can improve resource efficiency, encourage environmental stewardship, and support international efforts to achieve sustainable development goals by supporting a sustainable approach to food waste management.

Methodology

This thorough analysis of food waste in Saudi Arabia uses a multifaceted approach to investigate the effects on the country's economy and ecology. Starting with a thorough literature study, it establishes a baseline understanding of food waste challenges and best practices both locally and globally. Sources included are academic journals, government reports, industry publications, and international studies. To precisely measure food waste, surveys and questionnaires are sent to homes, companies, and organizations. Waste audits are also carried out in different industries to collect quantitative data. The dataset is further enhanced by secondary data from government databases and academic institutions. To get qualitative insights into the attitudes and practices surrounding food waste, semi-structured interviews with important stakeholders—including government officials, business executives, and representatives of non-governmental organizations—are conducted in addition to focus groups

with members of various community groups. Regression analysis is used to examine correlations between variables, descriptive statistics are used to spot patterns and trends, and cost-benefit analysis is used to evaluate the financial effects of food waste. Thematic analysis is used to find similar themes in focus groups and interviews with qualitative data, and content analysis is used to look for larger contextual insights in policy documents and media stories. In order to illustrate efficient tactics and procedures, the review also provides case studies of prosperous regional projects in Saudi Arabia along with comparisons with other countries' instances. Lifecycle analysis (LCA) is used in environmental impact assessments to examine the effects of food waste from production to disposal, while carbon footprint analysis is used to estimate greenhouse gas emissions related to food waste. Market analysis is used in economic impact assessments to determine how the food sector will be affected, social cost analysis is used to quantify the overall effects on society, and policy impact analysis is used to determine how well the current restrictions are working. Key obstacles are identified in the review, such as cultural norms that impact food waste behavior, inefficiencies in logistics and infrastructure, inadequacies in the legislative framework, and low public knowledge and education regarding food waste issues. Based on these conclusions, the review makes recommendations for targeted public engagement campaigns to encourage responsible consumption, technological advancements to improve food storage and waste management, policy interventions to support food waste reduction, and improved cooperation between government agencies, the private sector, and civil society to develop a comprehensive strategy for food waste management in the Kingdom.

Conceptual framework

Understanding the reasons for food waste in Saudi Arabia

A survey of the expanding body of studies on the causes of food waste in Saudi Arabia (Azazz et al. 2022), has revealed a number of variables that influence consumer behavior in this regard. Economic prosperity, consumer ignorance (Baig et al. 2022), the culture of food consumption, the lack of regulatory frameworks, food offers and promotions, individual attitudes toward food waste, social influence and perceived behavioral control, seasonal and special events, social media, and demographic factors are some of the contributing factors (Alsawah 2022). The ensuing subsections go further for the information about these elements.

Economic prosperity

In Saudi Arabia (SA), the state of the economy has been found to be a major influence on consumer behavior with regard to food waste (Baig et al. 2022). SA is well known

for having a thriving economy, which is mostly due to its substantial oil reserves, which place the nation among the world's top producers of oil. The Saudi Arabian government is dedicated to making sure that its people enjoy wealthy and high-quality lives in line with its 2030 Vision (The Saudi Vision 2030). As a result, the government sets price ceilings and provides subsidies to food producers in order to keep prices of goods and services fair for the benefit of its people (Alsawah et al. 2022). Because of the abundance of wealth in Saudi Arabia, people tend to buy more food than they need, which results in an excess of food that is left over and raises the country's rate of food waste (Baig et al. 2019b). It is so contended that food waste in Saudi Arabia is exacerbated by economic development.

Lack of awareness

The detrimental effects of food waste are not well understood by Saudi consumers, according to recent study (Baig et al. 2019b) on the topic of food waste in Saudi Arabia. There is no indication that consumer views on food waste have changed, despite government attempts to raise awareness among Saudis about the negative effects of food waste (Baig et al. 2022). It seems that these efforts have not had the desired effect. This implies that there is still room for improvement in the government's ability to educate the public about food waste. Furthermore, food service companies have a relatively small role in increasing customer awareness (Ouda et al. 2017). As a result, numerous research papers (Baig et al. 2022) have urged the government and food service companies to start media initiatives to raise consumer awareness of food waste. Furthermore, food service businesses play a critical role in reducing food waste by increasing employee and customer awareness, as highlighted by recent research (Azazz et al. 2022). When it comes to reducing food waste, staff and customer behavior is crucial. Food waste endures in Saudi Arabia despite the country's majority Muslim population, where people live their lives according to Islamic precepts. This runs against to religious beliefs. This led some researchers (Sobaih 2023) to look into how Saudi Arabians' level of religiosity affects their amount of food waste. Nonetheless, their results showed either a positive association or no discernible relationship between religiosity and food waste behavior (Van Geffen et al. 2020). This surprising outcome was ascribed to certain Saudis' ignorance of Islamic precepts, which encouraged them to buy excessive amounts of food and, as a result, contributed to the high percentage of food waste.

Food consumption culture

It is commonly known that food waste and the eating habits of Saudi Arabian consumers are related (Baig et

al. 2019b). As was previously mentioned, Saudi Arabians' low socioeconomic standing frequently causes them to engage in compulsive shopping, buying more goods than they can possibly use (Sobaih et al. 2023). People in Saudi Arabia tend to buy cooked cuisine or eat out more frequently due to the country's high-income levels (Baig et al. 2019b). It's generally been asserted that diners squander more food in restaurants than they do at home (Parizeau et al. 2015). Food waste practices are also greatly influenced by the societal norms surrounding food consumption (Ching-Hsu et al. 2020). People who are well-off, particularly in a country like Saudi Arabia where costs are considered reasonable, are more likely to make impulsive purchases (Sobaih et al. 2023). According to international research (Parizeau et al. 2015) customers who engage in these kinds of behaviors frequently don't care that food is wasted since they view it as a necessary component of their lifestyle. Likewise, studies carried out in the Saudi context (Sobaih et al. 2023) have confirmed that consumer behavior and eating habits have a significant role in food waste in nations such as Saudi Arabia. One important predictor of Saudi customers' desire to waste food is their cultural attitude of kindness and hospitality toward visitors and guests (Baig 2022). Therefore, encouraging sensible consumption habits can help cut down on food waste considerably.

Absence of legal frameworks

With a goal of 50% reduction in food loss and waste by 2030, the Saudi Vision 2030 has made food security a priority and included it in the national agenda (The Saudi Vision 2030). UN Sustainable Development Goal (SDG) 13.2, which aims to reduce global per capita food waste, is closely aligned with this effort. The Saudi Arabian government has launched the National Program for Food Loss and Waste Reduction to help achieve this goal [30]. Nevertheless, there aren't many published statistics about this program's effects. The government has started a number of programs and acted to address the problem of food waste in addition to the national program.

For example, the Shoura Council, a consultative body in Saudi Arabia, has called attention to the sizeable amount of food that is wasted in the nation and suggested fines for both customers and businesses that are accountable for this waste (Business 2021). However, there is currently no requirement requiring adherence to this guideline for anyone concerned in the management of food waste. Moreover, current studies, like the one done by (Baig et al. 2022) have verified that there isn't a legislative structure in Saudi Arabia that sanctions people or organizations for wasting food. According to Baig et al., one of the primary concerns is that there are still no such legal frameworks. On the other hand, nations like the USA, Italy, and France have put in place legislative

frameworks to deal with food waste. The United States passed the "Bill Emerson Good Samaritan Food Donation Act" in 1996 to encourage the gift of excess edible food to those in need, while France requires retailers to donate excess edible food to social and charity groups [32]. Similar to this, Italy has managed excess food since 2003 by enacting (Santeramo et al. 2021). In light of these instances, (Baig et al. 2022) recommend that regulations be created by the Saudi government to aid in the efficient management of food waste. This would support international efforts to reduce food waste and not only help solve the problem holistically but also be in line with the goals of the Saudi Vision 2030 (Mourad 2016).

Food offers and promotions

Food waste is a direct result of excessive food purchases, which are greatly influenced by food pricing (Tsalis et al. 2021). Low food prices frequently cause consumers to underestimate the value of food and to ignore the natural resources needed to produce it (Gjerris et al. 2013). Food is a low-effort, quickly-moving product, therefore a lot of consumers buy it on impulse and without giving it much thought (Bell et al. 2003). Furthermore, rather than out of need for money, shoppers might look for food deals as a representation of who they are (Jensen et al. 2017). While Katajajuuri et al.'s study (Katajajuuri et al. 2014) did not discover a direct correlation between food offers, reduced prices, and food waste, marketing tactics like "buy one get one free" promotions and package deals frequently lead to consumers buying more food than they need (Stuart 2009) This may result in overspending and overstocking food items, which could lead to wasted and unfinished goods. In conclusion, food promotions and deals may persuade consumers to purchase more food than they actually need, which raises the possibility of food waste should they be unable to finish it before it goes bad. It has been noted that Saudi customers buy an excessive amount of food (Ganglbauer et al. 2013). This can lead to food waste if improperly managed, especially when bulk food purchases are made.

Personal attitude

A review of the literature on the subject shows that subjective norms and perceived behavioral control are important elements that lead to food waste by persons (Ponis et al. 2017). Personal views regarding food waste are important in determining what people believe should be thrown out and what should be kept. A number of researches (Graham-Rowe et al. 2015), have demonstrated a significant correlation between individual attitudes and the desire to decrease food waste. Many people's intentions to waste less food are influenced by their belief that doing so can result in cost savings and other advantages (Elhoushy et al. 2020). Subjective

norms are the views of relevant persons or the perceived demands from society regarding particular behaviors (Comber et al. 2013). In Saudi Arabia, the collective cultural background means that subjective norms have a significant impact on food waste. Offering copious amounts of food to guests is a norm in Saudi culture, whether it be during formal visits or special occasions. People are frequently compelled by this societal expectation to prepare and serve more food than is necessary, which leads to an excess of food waste (Malibari et al. 2023). Additionally, it is considered improper by Saudi social norms and culture to gather leftover food from weddings or other social gatherings, which results in the waste of such food products (Ajzen 1991). Food waste is very common in Saudi society as a result of these cultural and societal factors.

Special events and seasons

Saudi Arabian culture places a high value on hospitality, especially when it comes to feeding family members and guests (Tobler et al. 2011). Saudi Arabians are known to buy food in large numbers and to give more food than is necessary. Giving food to visitors is regarded as a show of hospitality, particularly at occasions like celebrations, weddings, and festivals when extensive spreads of food are customarily made. In Saudi Arabia, for instance, the amount of food that is wasted at a single wedding could feed 250 hungry people (Kim et al. 2020.). A million people going hungry might have been fed in Makkah alone in 2016 (Russell et al. 2017). Food waste peaks at 70% during certain seasons and events, which are major contributors to the enormous volumes of food waste (Kautish et al. 2019). A significant amount of food waste is produced during holy occasions such as the month of Ramadan, when Saudis fast (Arab News 2016). The holy month of Ramadan is when food waste in Saudi Arabia peaks (Al-Fawaz 2022), accounting for the majority of garbage generated during this time (Zayat 2017). Saudi people cook a lot of food during Ramadan, which increases the number of leftovers (Shahzad et al. 2017). Furthermore, food waste tends to increase during social and religious occasions like Ramadan and the Hajj season, according to multiple research (Rehan et al. 2017).

Table 3 Environmental Impacts of Food Waste (Parizeau et al. 2015)

Environmental Impact	Metrics	Estimated Annual Impact in Saudi Arabia
Greenhouse Gas Emissions	CO ₂ equivalents	10 million tons
Water Usage	Liters per ton of wasted food	10 billion liters
Land Degradation	Hectares of land affected	10 thousand hectares

Social media and food waste

Research indicates that online shopping encourages impulsive buying (Amara et al. 2023), with a significant sum of money spent annually on unforeseen purchases—food being one of the most popular products in Saudi Arabia (Chamorro-Premuzic 2015). According to Aragoncillo and Orus (Aragoncillo et al. 2018), social networking sites also have an impact on impulsive purchases and excessive food consumption. The increasing popularity of seeing food preparation or photography on social media platforms may have contributed to this influence (Azazz et al. 2022). In an effort to sample new foods, this tendency frequently causes consumers to overbuy food (Khokhar et al. 2019), which raises the rate of food waste (Zafar et al. 2020). Among the detrimental effects of social media on food waste are the promotion of overconsumption (Omar et al. 2021) the emergence of influencer marketing (Teoh et al. 2022) and the creation of food FOMO (fear of missing out on trendy foods), all of which affect consumer behavior and raise food waste. It’s crucial to remember, too, that social media may also greatly reduce food waste by raising awareness and motivating acts like giving extra food to people in need (Jorissen et al. 2015). Social media platforms may significantly contribute to encouraging ethical consumption practices and reducing food waste through a variety of means.

Demographic factors and food waste

Fast food restaurants are becoming more and more common in Saudi Arabia; in 2017, sales are expected to reach USD 6.9 billion (Koivupuro et al. 2012). There are a number of reasons for this spike in demand for fast food restaurants, including the rising numbers of young people and women entering the workforce. Because around 70% of Saudis are under 30, and because more women are joining the workforce, people’s lifestyles have changed, leaving less time for home cooking. The success of these eateries has also been aided by the influence of Western consumerism (Alshuwaikhat et al. 2017). Furthermore, compared to eating at home, customers tend to abandon more products when dining at restaurants, according to studies by (Parizeau et al. 2015). Several studies (Al-Fuhaid 2013) have shown that household size is another factor related to food waste, with smaller households often producing less waste than larger ones. To validate this assertion and delve into the subtleties of its connection to food waste, more research is necessary. The impact of food waste on the environment is shown in Table 3 and its economic impact is shown in Table 4.

Potential strategies for KSA and remedial measures Panel of experts and the committee to reduce food waste

A group entrusted with researching workable ways for decreasing food waste in a sustainable manner was

Table 4 Economic Costs of Food Waste (Parizeau et al. 2015)

Economic Impact	Cost Components	Estimated Annual Cost in Saudi Arabia
Waste Disposal Costs	Cost per ton of food waste disposed	\$10 million
Lost Revenue	Retail and hospitality sector losses	\$10 billion
Environmental Cleanup	Cost of environmental remediation	\$10 million

established by the Ministry of Food and Agriculture in Riyadh, which recognized the grave consequences of food waste (Aziz, Afshan, 2012). This committee has been charged with the responsibility of looking at the food supply chain to find places where food waste may be reduced and creating systems to reduce food waste in society as a whole because it has a negative effect on the Kingdom's natural resources, especially groundwater. Addressing inefficiencies in the food supply chain is one of the ministry's mandates, and compared to other aspects of its directive, this one may not pose as many difficulties. Furthermore, Saudi Arabia plans to initiate a broad campaign to increase public awareness of the significance of reducing food waste in a variety of settings, including homes, restaurants, hotels, canteens, and cafeterias at schools and universities (Baig et al. 2016). These programs, which focus on both institutional and individual behavior, aim to establish a culture of accountability and sustainability in food management and consumption throughout the Kingdom.

Regulation and elevating of prices of food commodities and food disposal

It's possible that raising the price of food will improve its perceived worth and, as a result, decrease waste in the supply chain. But it's important to consider the possible effects on disadvantaged populations in the Kingdom of Saudi Arabia (KSA). Policies must be crafted with the intention of minimizing any negative impact on marginalized groups, guaranteeing that everyone has fair access to necessities. Moreover, it is crucial to put laws into place that establish efficient food waste management techniques at the local level. Imposing a food waste disposal fee on parties involved who plan to dispose of food waste in landfills is one possible solution. Regulations to limit the amount of organic carbon in garbage that is going to be disposed of in landfills could also be implemented. This strategy, which is comparable to that used by the Austrian government in accordance with its Federal waste regulations, entails reducing the amount of organic waste to an extremely low value, requiring garbage to be pre-treated before being disposed of in a landfill (Chatham House, 2013). Implementing such policies

lowers methane emissions from landfill microbiological processes and promotes the separate collection of food waste and biological pre-treatment. These rules help to maintain environmental sustainability by encouraging appropriate waste management techniques and lessen the harmful effects of food waste on the environment and public health.

Potential role of extension education

One of the most practical ways to reduce food waste is to raise public knowledge of the issue of food waste and its effects on sustainability, with a particular emphasis on the water situation in the Kingdom of Saudi Arabia (KSA), through engaging extension education programs. A large percentage of food waste in the Kingdom of Saudi Arabia can be traced back to a cultural dearth of attention on the value of food conservation and its consequences for sustainability and the environment. Raising awareness in families and society at large is necessary to address this issue, especially with relation to imported food items like rice. In order to combat food waste, Saudis ought to investigate means of making use of excess food that regular people discard. While it might be difficult to totally stop food waste, strong public awareness campaigns and extension education initiatives can help to significantly reduce it. To prioritize food conservation, attitudes in both the personal and economic spheres must change (La Legge del Buon Samaritano 2003). Because Islamic teachings have a strong hold on Saudi society, public debate can benefit by quoting pertinent verses from the Quran, such as 7:31, which emphasizes the need of avoiding wastefulness. Given that a sizeable amount of food in the Kingdom is imported, it is essential to launch a nationwide campaign encouraging food conservation and sensible consumption. In addition to houses, establishments such as hotels, restaurants, and educational institutions should be the focus of this effort. When it comes to planning workshops and conferences with planners, legislators, civic society, youth organizations, and women's groups, the Extension Department can be a key organizer. However, broad public support and the effective use of suggested tactics are necessary for these programs to be successful. It is imperative to educate all members of society about the value of food through specialized programs that are modeled after globally successful initiatives like the UK's Love Food Hate Waste campaign. Carefully tailoring these efforts to the unique circumstances and cultural milieu of the Kingdom of Saudi Arabia is imperative. The KSA can significantly reduce food waste and promote sustainability by cultivating a culture of food conservation and accountability.

Framing of laws and formulation of policies supporting food surplus redistribution

In fact, the lack of laws in the Kingdom of Saudi Arabia prohibiting littering or disposing of food waste emphasizes the necessity of government action to reduce food waste in the food chain. The Ministry of Food and Agriculture ought to take the initiative to draft legislation and regulations that would reduce food waste, especially through the unit it has committed to the cause in the Kingdom. Adopting laws and imposing fines on those who participate in food waste could be one strategy. Laws that forbid homes from carelessly discarding fruits and vegetables could possibly be established to restrict the processing of food waste and agricultural products in Saudi Arabia. Alternatively, legislation requiring the proper disposal of food products could be proposed, guaranteeing that excess food is handled appropriately. France's 2016 enactment of a law prohibiting food waste from stores serves as a possible model for such a framework (Saudi Gazette 2016). Retailers are required by law to give edible excess food to charitable groups so that it can be given to the less fortunate. Comparably, the United States of America enacted the "Bill Emerson Good Samaritan Food Donation Act" in 1996, which permitted charitable organizations to provide extra food to underprivileged individuals. Since 2003, Italy has also passed laws addressing food waste (Arab and News 2013). Saudi Arabia may create comprehensive legislation to successfully reduce food waste, encourage responsible consumption patterns, and support sustainability efforts by taking inspiration from these examples. In addition to lowering food waste, these measures would encourage resource conservation and social responsibility throughout the Kingdom.

Employing extension methods and its tools to create awareness

It is true that using park signage and roadside billboards as extension tools can help to educate the public, increase awareness, and encourage dietary changes related to food waste. The public is constantly reminded by these visual media of the value of decreasing food waste and promoting sensible consumption practices. Furthermore, one of the most effective ways to reduce food waste is to start anti-food waste awareness campaigns through a variety of media channels. These channels include print media like pamphlets, newspapers, and magazines, as well as traditional electronic media like TV, radio, and mobile phone messages. These advertisements have the potential to reach a large audience and provide focused messages regarding the negative effects of food waste and the value of conservation. Moreover, the utilization of social media platforms like Facebook, Twitter, and YouTube can augment the outreach and influence of campaigns against

food waste, especially with younger populations who are frequent users of these sites. Infographics, interactive articles, and educational movies are examples of engaging content that can effectively communicate a message and motivate people to take part in initiatives to reduce food waste. Considering that the majority of Saudi Arabia's population is Muslim, imams can have a significant impact by including sermons on reducing food waste during Friday prayers. Reaching a sizable segment of the populace, this religious platform can reaffirm the moral and ethical necessity of preserving food supplies. Furthermore, teaching future generations about sustainability and responsibility through lectures and educational programs on food waste reduction in schools, colleges, and universities can support these efforts. Saudi Arabia has the potential to effectively minimize food waste by promoting a shift in societal consumption behaviors and utilizing diverse communication channels to spread anti-food waste messaging.

Extension education programs organized by private organization like it'aam

It'aam Food Charitable Society deserves praise for raising awareness of the value of food conservation through its Extension Education Programs. Because they encourage responsible consumption and lessen food waste, these awareness programs may benefit society and the country's economy. By entering into Memorandums of Understanding with government agencies like Saudi Aramco and the Saudi Press Agency, It'aam Food Charitable Society broadens its audience and uses a variety of media to spread its message. Working together with these organizations enables more information to be shared widely and engages a variety of audiences from various societal sectors. The dissemination of the journal "Meerah" is an additional step in the society's outreach initiatives. The society successfully spreads the word to readers and the broader public to "Do not waste food" through this publication. Raising awareness and encouraging behavioral change, the magazine is a great resource for sharing food conservation-related tales, facts, and advice. Furthermore, by giving extra food to people in need, the food donations made possible by It'aam Food Charitable Society not only assist in addressing current food insecurity but also help reduce food waste. By making sure that extra food is consumed instead of thrown out, society adheres to social responsibility and sustainability ideals. Overall, through its extension education initiatives, collaborations with government agencies, and informational distribution through "Meerah" magazine, It'aam Food Charitable Society plays a critical role in eliminating food waste and encouraging food conservation. Through effective resource use, these initiatives support the national

economy and help to create a more caring and aware society.

Planning for groceries, stop over-buying and extra cooking

Families are essential in decreasing wasteful behavior, which begins with over shopping and cooking large amounts of food. Through the implementation of strategic initiatives, families can reduce food waste and encourage more economical consumption practices. Meal planning, in which families set out their weekly menus and make grocery lists based on actual needs, is one useful tactic. This ensures that only necessary things are purchased in appropriate quantities and helps prevent impulsive purchases. Furthermore, food waste can be avoided by paying attention to use-by dates rather than only safety dates. Eating food prior to its expiration date minimizes the risk of spoiling and encourages sensible consumption. An additional strategy is to recycle leftovers by adding them to other meals or creating new dishes with them. This increases meal variety while also cutting down on food waste. Moreover, the concept of keeping food on hand for unforeseen visitors can be handled by employing kitchen gadgets like microwaves and freezers. To accommodate guests, extra food can be swiftly prepared, adding to the pleasure of friendly visits without adding to food waste. Families in Saudi Arabia can contribute to a more sustainable food system and drastically reduce their food waste impact by implementing these techniques. Fostering conscientious consumption practices in households is crucial to tackling the more extensive problem of food waste and advancing an innovative and eco-friendly culture.

Focus on youth and women

With women and youth making up a large share of Saudi Arabia's population, focused communication initiatives are crucial for promoting positive behavioral changes with relation to food waste. Given that civil society is dominated by traditional, collective, and conservative values, it is imperative that corrective actions be designed in a way that conforms to these cultural norms. The animated short videos that the It'aam charity group has produced for kids are a noteworthy endeavor that involves the younger demographic in an enjoyable and informative style. The organization makes sure that kids hear the message about reducing food waste at home and in school by reaching out to teachers as well. For food waste reduction awareness programs, women—who frequently bear the major duty for food management and cooking in households—represent a crucial target demographic. Using morning TV shows, which women frequently watch at home, can be a useful tool for spreading knowledge and promoting positive behavior changes. In a similar vein, since young people use cell phones a lot, sending

extension messages to them through mobile devices can also efficiently target this population. Awareness campaigns can effectively permeate society and bring about significant changes in attitudes and actions regarding food waste by leveraging these widely available communication channels. Overall, to maximize the impact of awareness programs on reducing food waste, focused communication initiatives that address the unique cultural norms and demographics of Saudi society are crucial. Through the use of suitable media and message, groups such as It'aam can significantly contribute to the development of a sustainable and conscientious consumption culture within the Kingdom.

KSA – the multilingual region

It is true that involving the expatriate and foreign worker population in Saudi Arabian awareness and education efforts about reducing food waste can have a major and beneficial effect. Including the nation's roughly 10 million expatriates and foreign workers in these initiatives guarantees a more thorough and varied outreach endeavor. Since most expatriates in Saudi Arabia come from a multicultural background, reaching and engaging this group requires message delivery in various languages. This strategy fits in nicely with the Kingdom's efforts to become a bilingual nation since it makes it easier to communicate with people who speak different languages. Organizations and projects supporting food waste reduction can effectively interact with expatriates and abroad workers by broadcasting awareness messages in multiple languages. This ensures that the workers are informed and empowered to contribute to sustainability efforts in the Kingdom. Including the expat and foreign worker community in awareness programs broadens their audience and promotes a sense of inclusivity and shared accountability in tackling environmental issues like food waste. Ultimately, Saudi Arabia can strengthen its efforts to create a society that is more environmentally conscious and sustainable by including diverse communities in group action.

Managing left-over at the restaurants

There are particular difficulties in preventing food waste in hotels and restaurants because a large amount of food preparation is done ahead of time and leftovers are frequently inevitable. Nonetheless, there are a number of tactics that businesses may use to reduce waste and encourage sustainability. Polite reminders in cafeterias, restaurants, and buffets can help reduce food waste by reminding customers to watch portion sizes and not overorder. Furthermore, a few eateries have effectively instituted strategies like upselling clients for partially consumed dishes, encouraging them to order only what they can finish. Mobile apps can be useful resources for

involving youth and encouraging the reduction of food waste, based on lessons learned from experiences in other nations. Apps such as “Too Good to Go,” which are accessible in a number of European nations, allow customers to buy restaurant surplus food at a discount, minimizing food waste and its negative environmental effects. Millions of meals have been saved thanks to this creative strategy, which has also significantly decreased CO₂ emissions. Through the implementation of various tactics including polite follow-ups, creative guidelines, and mobile applications, Saudi Arabian hotels and restaurants may significantly contribute to the fight against food waste and the advancement of sustainability in the hospitality sector. Working together, businesses, customers, and digital platforms can promote a more conscientious attitude toward food consumption and waste disposal.

Setting up a food charitable society

In the Kingdom of Saudi Arabia (KSA), food redistribution programs like those run by The It'aam Food Charitable Society are essential for reducing food insecurity and eliminating food waste. By distributing extra food to people in need, these programs not only assist minimize food waste but also uphold the charitable traditions of Islam, which emphasize compassion and social responsibility. The formation of food banks in several KSA cities, in addition to individual initiatives aimed at curbing food waste and aiding the underprivileged, is indicative of the proactive stance citizens have taken in addressing societal issues. A dignified solution for those experiencing food insecurity is offered by programs like the installation of communal refrigerators, where anyone can donate and obtain food anonymously. These initiatives also promote a sense of community solidarity. Raising awareness and promoting broad participation throughout the Kingdom are crucial for maximizing the impact of such efforts. Communities can efficiently deploy resources to address food waste and food insecurity concurrently by endorsing and reproducing successful methods of

food redistribution. Furthermore, although there may not be financial incentives for food contributions in the Kingdom of Saudi Arabia at the moment, governmental actions to encourage and facilitate food redistribution initiatives could potentially increase their efficacy. Through a combination of community-based programs and official assistance, the Kingdom can strive toward a more just and sustainable food system that serves the interests of all citizens.

Developing composting or biogas facilities

Managing inevitable food waste and lessening its environmental impact can be accomplished in a practical way by implementing composting facilities at the municipal and household levels. Food waste can be converted into nutrient-rich compost that can be added to soil to improve fertility and encourage plant development by composting it locally. The government should implement incentive programs that support the separate collection and composting of food waste in order to promote the widespread adoption of composting practices. This could take the form of tax reductions for homes and municipalities who engage in composting programs or subsidies for composting equipment. It's vital to remember that because food waste has a high-water content, it might not always be appropriate for conventional aerobic composting. Therefore, to ensure the best input quality for the composting process, a varied mix of organic wastes should be considered. As an alternative, tiny biogas facilities can offer an additional environmentally friendly way to handle food waste. These plants have the ability to transform organic waste—including food waste—into biogas, a green energy source. Composting the solid wastes generated during the biogas generating process can improve the quality of the soil even further. The Kingdom can efficiently manage food waste, exploit renewable energy resources, and promote soil health and sustainability by combining composting and biogas technology as shown in Fig. 2.

Discussion

Food waste is a global issue with substantial effects on the economy, society, and environment. The problem of food waste has gained more attention in the context of Saudi Arabia, a nation undergoing fast economic development and changing consumption habits. Comprehending the intricacies associated with food waste in Saudi Arabia necessitates an extensive examination of its obstacles, decisions, and the consequent effects on the environment and economy.

First, determining the amount of food waste in Saudi Arabia is essential to comprehending the scope of the issue. Food waste in the nation has been attempted to be quantified and characterized in research investigations

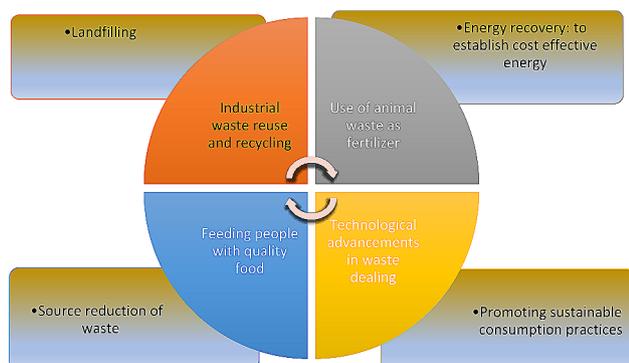


Fig. 2 Management of food waste by various means in Saudi Arabia

like (Al-Ghamdi et al. 2020). These studies demonstrate the various origins of food waste, which include supermarkets, restaurants, homes, and agricultural production. Through the implementation of waste audits and advanced data analytics, scholars have acquired significant knowledge regarding the trends and factors contributing to food waste along the whole supply chain. Food waste habits in Saudi Arabia are mostly determined by cultural and behavioral variables. Saudi Arabian hospitality is profoundly ingrained in the country's culture, and as a result, elaborate meals and large portions are frequently served, which increases the production and waste of surplus food. Additionally, religious holidays like Ramadan increase food waste during celebrations. Targeted interventions that encourage ethical consumption while honoring ethnic customs are necessary to address these cultural idiosyncrasies. According to (Al-Kharusi et al. 2021; Russell et al. 2019), strategies could include rewards that are in line with cultural values, educational initiatives, and customized message campaigns.

Reducing waste and increasing resource efficiency require optimizing the food supply chain. Since a large amount of food in Saudi Arabia is imported, streamlining distribution and logistics networks can help cut down on losses and spoiling from transportation. Putting inventory management systems in place and making investments in cold chain infrastructure are crucial first steps in this direction. The significance of supply chain optimization in lowering food waste at all production and distribution phases is emphasized by (Afshari et al. 2020). Frameworks for regulations and policy are essential for encouraging sustainable practices and providing incentives for waste reduction. The National Transformation Program and Saudi Vision 2030 offer tactical frameworks for incorporating food waste management into more comprehensive sustainability programs. Setting goals for landfill diversion and enacting laws requiring enterprises

to disclose food waste can provide stakeholders the motivation they need to give waste reduction projects top priority. Technological advancements present possible answers to Saudi Arabia's problems with food waste. A few examples include smart packaging technologies that prolong the shelf life of perishable commodities, mobile applications that link surplus food farmers with charity, and biorefinery technologies that turn organic waste into products with additional value. (Ghose et al. 2019; Aschemann-Witzel et al. 2015) talk about how technology advancements can help reduce food waste and increase resource efficiency. Promoting sustainable consumption practices and behavior change need raising public awareness and educating the public. Educating people about the negative effect's food waste has on the environment, the economy, and society through community workshops, educational campaigns, and school programs can encourage people to make thoughtful consumption choices for themselves and their families. Working together with influential members of the community, religious leaders, and educational institutions can help spread the word about waste reduction and inspire group action. Table 5 shows the comparison on the strategies of food reduction in Saudi Arabia.

In summary, tackling food waste in Saudi Arabia necessitates a thorough strategy that combines technological know-how with sociocultural understanding. Stakeholders can create comprehensive strategies to reduce waste generation, conserve resources, and advance sustainable development in the Kingdom by embracing technological innovations, optimizing the supply chain, calculating food waste, comprehending cultural and behavioral factors, adopting policy interventions, and increasing public awareness. The application of a wide range of cutting-edge technology suited to various phases of the food supply chain can improve Saudi Arabia's efficacious control of food waste. These solutions allow for real-time monitoring and analysis of food waste patterns, starting with smart waste bins that are outfitted with sensors and data analytics platforms. This empowers households and companies to improve their consumption behaviors. Aerated static pile systems and in-vessel composting are two examples of composting technologies that efficiently break down organic waste into nutrient-rich compost that may be used in farming. Large-scale biogas plants and smaller home digesters alike, as well as other anaerobic digestion facilities, transform organic waste into biogas and fertilizers to promote the creation of renewable energy and sustainable farming methods. Advanced incineration, gasification, and pyrolysis are examples of waste-to-energy technologies that help recover energy from garbage and lower greenhouse gas emissions by lowering the need for landfills. In addition, cutting-edge packaging techniques like active and edible packaging

Table 5 Comparison of food waste reduction strategies (Ghose et al. 2019)

Strategy	Description	Benefits	Challenges
Source Reduction	Minimizing waste at the production and consumption stages	Reduces overall waste generation	Requires behavior change
Food Redistribution	Donating surplus food to charities and food banks	Addresses food insecurity; social benefits	Logistics and food safety concerns
Composting	Turning organic waste into nutrient-rich compost	Improves soil health; reduces landfill waste	Requires infrastructure investment
Anaerobic Digestion	Converting organic waste into biogas and fertilizer	Generates renewable energy; reduces emissions	High initial costs; technology upkeep

improve food preservation and lower spoilage. These techniques are combined with precision agriculture technology and smart refrigeration units to preserve food quality all the way through the supply chain. In addition to reducing food waste, these integrated technological solutions seek to optimize resource efficiency and environmental sustainability throughout Saudi Arabia's food industry.

Conclusions

In conclusion, the analysis of Saudi Arabia's food waste plans and difficulties highlights the critical need for thorough and coordinated efforts to address this important problem. It has become clear from this study that food waste causes significant economic harm due to inefficiencies in production, distribution, and waste treatment, in addition to environmental problems including greenhouse gas emissions and resource depletion. Food waste trends are significantly shaped by cultural norms and consumer behavior, underscoring the significance of focused educational initiatives and behavioral treatments. The investigation of several technical remedies, ranging from sophisticated composting and waste-to-energy technologies to intelligent waste management systems, presents auspicious opportunities for mitigating food waste and optimizing resource recuperation. In addition, the assessment highlights how policy frameworks and regulatory actions can encourage sustainable practices across industries and promote cooperation between public agencies, private businesses, and civil society organizations. Going forward, sustained funding for public participation, infrastructure development, and research will be necessary for the successful application of these initiatives. Through the implementation of a circular economy strategy that places emphasis on waste prevention, byproduct valuation, and sustainable consumption patterns, Saudi Arabia can effectively address the environmental consequences of food waste while simultaneously improving food security, fostering economic resilience, and supporting worldwide endeavors towards sustainable development. In the end, tackling food waste in Saudi Arabia offers a chance to turn obstacles into chances for sustainability and innovation, guaranteeing a more robust and wealthy future for future generations.

Future prospective

There are a number of directions that future study and initiatives might take to alleviate food waste in Saudi Arabia.

First and foremost, in order to precisely determine the amount and range of food waste in various economic sectors, more thorough data and research are required. This entails carrying out thorough waste audits, looking into

trends in consumer behavior, and assessing the effectiveness of food supply networks.

Second, to reduce food waste at every level of the supply chain—from production and distribution to consumption and disposal—targeted interventions should be the main focus of future efforts. This could entail creating laws and rules to promote waste minimization, making infrastructure investments for the recovery and redistribution of food, and encouraging sustainable consumption habits.

Thirdly, there is a need for increased coordination and cooperation between all parties involved, which includes companies, consumers, civil society organizations, and government authorities. Together, these parties can make the most of their combined knowledge and assets to put practical solutions into place and bring about significant change.

In summary, tackling food waste in Saudi Arabia necessitates a multifaceted strategy that incorporates social, economic, and environmental factors. Through creative thinking, teamwork, and education, Saudi Arabia can lessen its environmental impact, open up new business prospects, and support international efforts to promote sustainable development.

Author contributions

The idea was developed by M. Amin Mir, data collection by Chang and Duaa. Final manuscript was made by all these authors.

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Informed consent

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Conflict of interest

There is no conflict of interest among the authors.

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