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عنوان البحث

The Importance of Health, Safety and Environment in Petrochemical industries (Plastic plants
producing Food Grade) at Yanbu Industrial Area

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Dedication

If this research holds any value, it is first and foremost by the grace of God, who granted me strength and perseverance throughout this academic journey.

I dedicate this work to the my father and mother, whom prayers, wisdom and unwavering me all the required support and inspiration during my academic journey.

To my dear wife, my partner in every challenge, whose patience and belief in me were my greatest motivation.

To my siblings, who stood by me with endless support and encouragement.

To my mentors and professors, whose guidance and knowledge shaped my academic path.

And to all those who believed in me, encouraged me, and contributed to this accomplishment - this work is for you.

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Abstract

This study investigates the health, safety, and environmental (HSE) aspects of plastic materials used in food applications in Yanbu. A descriptive-analytical methodology was adopted, utilizing a structured questionnaire distributed to a diverse sample of 1,406 participants, including consumers, industry workers, and food packaging professionals. The study aimed to assess the safety of food-grade plastics, evaluate potential health risks from chemical migration, and measure the alignment between local industrial practices and international HSE standards. The findings revealed significant health concerns related to chemical leaching, particularly when plastic containers are exposed to heat. Environmental risks were also highlighted due to inadequate recycling infrastructure and the prevalence of single-use plastics. Additionally, a notable gap was identified between current practices and global safety benchmarks. The study recommends enhancing national regulations and enforcement mechanisms, promoting the circular economy in the plastic sector, and launching awareness campaigns to educate both consumers and industry stakeholders. Implementing these measures would support safer food storage, reduce occupational hazards in plastic manufacturing, and mitigate the environmental burden of plastic waste. The research contributes to ongoing efforts aligned with Saudi Vision 2030 to improve public health, environmental sustainability, and industrial innovation.

Keywords:

Food-grade plastics, Health and safety risks, Environmental sustainability.

المستخلص

تهدف هذه الدراسة إلى تقييم الجوانب الصحية، والسلامة المهنية، والبيئية (HSE) المرتبطة باستخدام المواد البلاستيكية في تطبيقات الأغذية في مدينة ينبع. استخدم الباحث المنهج الوصفي التحليلي، مع الاعتماد على أداة الاستبانة كأداة رئيسية لجمع البيانات. وقد شملت العينة 1406 مشاركاً من فئات متعددة شملت مستهلكين، ومصنعين، وعاملين في قطاع التغليف الغذائي، ما أتاح تنوعاً في وجهات النظر. سعت الدراسة إلى تحقيق عدة أهداف، أبرزها: تقييم مدى سلامة المواد البلاستيكية المستخدمة في تغليف الطعام، وتحليل المخاطر الصحية الناتجة عن الهجرة الكيميائية من البلاستيك إلى الغذاء، وقياس مدى التوافق بين الممارسات المحلية والمعايير الدولية في مجال HSE. أظهرت النتائج وجود تأثيرات صحية محتملة نتيجة استخدام البلاستيك في ظروف غير مثالية، خاصة عند تسخين الطعام، بالإضافة إلى مخاطر بيئية متزايدة بسبب ضعف نظم إعادة التدوير. كما بيّنت النتائج فجوة ملحوظة بين الممارسات الصناعية الحالية والمعايير الدولية للسلامة. أوصت الدراسة بضرورة تطوير التشريعات الوطنية، وفرض رقابة فعالة على صناعة البلاستيك الغذائي، وتبني مبادئ الاقتصاد الدائري، إلى جانب رفع مستوى الوعي المجتمعي عبر حملات توعوية وتدريبية شاملة. تسهم هذه التوصيات في حماية صحة المستهلك، وضمان بيئة عمل آمنة، وتقليل العبء البيئي الناتج عن البلاستيك.

الكلمات المفتاحية:

السلامة والصحة المهنية، البلاستيك الغذائي، الاستدامة البيئية.

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CHAPTER 1

Introduction

The prevalent tendency of using plastics in the food industry became essential to the modern consumption trends over the recent decades worldwide, including Saudi Arabia. The use of plastic in food packaging and containers, food utensils, and food processing materials is carried out because of the properties of these plastics; which include lightweight, cheap, and easy to handle. Nonetheless, although without debate, the net result of the use of plastics in food logistics and its economics has been beneficial, mounting sentiments have been raised over their possible effects on human health, sustainability of the environment and the safety of workplaces. The study examines the Health, Safety, and Environmental (HSE) issues of the plastic materials applied to food-related practices by considering the practice, risks, and policy imbricated to the Saudi Arabian context.

Chemical migration: Chemical migration, which is migration of undesirable substances in the plastic packaging into food, is one of the major issues associated with food-grade plastics. Many studies have noted the possible implications of the health hazards that may be posed by the occurrence of the said ingredients and chemicals. Recently, Adly et al. (2025) carried out a study in Saudi Arabia investigating a series of hydrocarbons with aromatic rings called polycyclic aromatic hydrocarbons (PAHs) and other chemical compounds that migrated in food packaging materials like plastics. Their observations show the proposition that consumers might be exposed with quantifiable amounts of hazardous chemicals by simply using plastic containers, which are expandable risks in food safety and possible long-term health implications. The paper has pointed to the need to increase the degree of regulating standards and the entire process of safety testing, particularly to protect the consumer in the Kingdom.

Along with the issues of human health, the environmental consequences of using plastic, in particular, the packaging that is meant to be used once, become more and more disturbing. Food related plastics lead to voluminous amounts of solid waste most of which are non-biodegradable and which linger in the ecosystems even after centuries. Researchers stressed the fact that plastic waste produced by food and healthcare products presents a threat to the environment, as well as the health of the population (Ugoeze et al., 2021). They have reviewed the cumulative impact of poorly managed plastic waste in developing and emerging economies (with low recycling infrastructure and unawareness-levels exacerbating the situation). The problem of plastic waste has increasingly challenged the environment in Saudi Arabia where consumer culture is obsessed with convenience packaging and takeaway foods

services. Industrial and municipal sectors are being compelled to go green and minimize their use of non-recyclable resources.

Furthermore, the safety aspect of plastic processing and handling in the industry is worth giving an eye to. Although plastics are flexible and functional in food related manufacturing, the manufacturing process comes with some occupational hazards and some of the hazards to be considered are exposure to chemicals, heat and equipment hazards. Elete et al. (2024) note that in the framework of industrial activity, which is the implementation of coatings, treatment, or the production of packaging film, HSE standards should be developed to a new level in order to keep the workers safe and observe the requirements of international safety standards. In the fast growing industrial cities of Saudi Arabia such as Yanbu and Jubail, there is existing emergency to find ways and means of tightening the safety management system, safety training programs and risk reduction strategies in the plastic manufacturing factories, especially food grade plastics manufacturing units.

Plastic usage in the food system also requires the systemic transformation to more circular and environmentally friendlier solutions on the broader level of environmental sustainability. Mazzi (2023) introduced a unified approach to environmental and safety risk assessment to plastic production and suggested redesigning the usual linear lifecycle of plastic materials with circular production cycles. The major focus of these models is to limit materials waste, energy utilization and recyclability. Such practices are in line with the national plans such as Vision 2030 of Saudi Arabia that is aimed at reinforcing the environmental stewardship and industrial innovation. Nonetheless, the sensible application of the principles of the circular economy to the plastics industry is not constantly followed through, as it is usually blocked by cost-effectiveness, regulatory uncertainty, and consumer ignorance.

Newer ways are already taking shape in the international scene, and these approaches will present an encouraging solution to the multifaceted challenges of HSE related to the use of plastics. Green solvent and separation processes are also one such innovation along with substances to make it possible to recycle multilayer plastic films, which are used as common components in food packaging. Ikegwu et al. (2024) proved the possibilities of science to innovate the process of recycling plastic, using computational modeling and process engineering, with no sacrifices in safety or performance of the process. In the same token, Faraz et al. (2024) have raised the issue of the increased importance of organic nanomaterials in food packaging and covered the opportunities and regulatory issues that might play out

once organic nanomaterials become widely adopted. The mentioned developments demonstrate how dynamic the field of HSE considerations is and indicate the need to research and policy frameworks that can be used to ensure responsible innovation in the Saudi environment.

Summing up, it is necessary to mention that plastics remain a critical component of the food industry, yet the effect on health, safety, and the environment is so important that its investigation should be conducted as soon as possible and thoroughly. In this study, the researcher attempts to fill this gap by establishing the level of risks, laws and practices involved in the use of plastics in food in Saudi Arabia. Analyzing scientific legit, processes, and codes of practices, the study will attempt to provide pragmatic guidelines to ensure that the consumers are safe, the working environment is secure, and the environment is sustainable in relation to the national development agenda.

Research Problem

The application of plastic in food has brought about concerns of severe impacts with regard to health, safety and environmental effects of using it. Although plastic packaging is still necessary to help maintain the quality of food, prolong its shelf life and minimize contamination, recent research has brought out unintended dangers of plastic packaging. The migration of chemicals of the plastic to the food is one of the key problems. As shown by Adly et al. (2025), food-grade plastics might release polycyclic aromatic hydrocarbons (PAHs) and other dangerous elements during regular use, which endangered the consumer health. This is particularly serious in warm areas like Saudi Arabia since the elevated temperature may speed up the leaching of chemicals.

The environmental issues are also severe. Rising usage of plastic food and wrapping packages is also one of the greatest contributors of non-biodegradable wastes. According to Ugoeze et al. (2021), there is no doubt that food packaging waste is one of the most resistant environmental pollutants, and it may most of the times block drainage channels, pollute marine life, and even indirectly expose humans through the food chain. With urban population development, in such a rapid way and high rates of dependence on disposable food packaging, Saudi Arabia is feeling increased pressure to fix this problem.

Otherwise, there are also occupational hazards in the production and processing of the food-grade plastic during safety terms. Similarities might be found in the arguments of Elele et al. (2024) and Mazzi (2023), who both present the necessity of prioritizing the enhancement of industrial HSE (Health, Safety, and Environment) standards, particularly in those geographical regions where such regulations could be inconsistent. Although the world has come a long way in terms of HSE frameworks, such assessments remain incomplete at a local level especially in the case of Saudi Arabia whereby research on determining the safety of food-grade plastic is sparse.

Considering these issues, one of the gaps that cannot be yet overcome is the assessment of the compatibility of the plastics utilized in Saudi Arabian food applications with the leading standards in the international HSE standards. Accordingly, the most important research question of the given research study is:

To what extent do plastics used in food applications in Saudi Arabia comply with global health, safety, and environmental standards?

Importance of Research

Scientific Significance

- Contributes to the existing body of knowledge on the health, safety, and environmental risks associated with food-grade plastics.
- Highlights the chemical interactions between plastic materials and food substances, which are often understudied in local contexts.
- Supports future scientific investigations in the field of material safety and sustainable food packaging technologies.
- Encourages interdisciplinary research linking public health, environmental science, and industrial safety.

2. Practical Significance

- Informs manufacturers, policymakers, and consumers in Saudi Arabia about the safe use of plastic materials in food applications.
- Offers recommendations that can be applied in regulatory development, food safety protocols, and industrial standards.
- Helps industries identify and mitigate risks in plastic processing, usage, and disposal.
- Contributes to raising public awareness regarding safe food storage practices and the environmental impact of plastic waste.

Study Objectives

- To assess the safety of plastic materials used in food packaging and utensils.
- To evaluate the potential health risks associated with daily exposure to food-grade plastics.
- To analyze the environmental implications of plastic production, usage, and disposal within the Saudi context.
- To measure the extent of alignment between local plastic industry practices and international HSE standards.
- To propose actionable recommendations for safer production, usage, and disposal of plastics in the food sector.

Study Questions

Main Question:

- To what extent do plastics used in food applications in Saudi Arabia comply with global health, safety, and environmental (HSE) standards?

Sub-Questions:

- Is there a measurable health impact on consumers due to chemical migration from food-grade plastic?
- Are the plastic products used in food applications manufactured in accordance with recognized safety protocols?
- How does the use of food-grade plastics contribute to environmental pollution and waste management challenges?
- What level of awareness do industry professionals and consumers have about the health and environmental risks associated with food plastics?

Study Hypotheses

Main Hypothesis:

- There is a statistically significant relationship between the use of food-grade plastics in Saudi Arabia and their compliance with international health, safety, and environmental standards.

Sub-Hypotheses:

- There is a statistically significant impact of chemical migration from plastic packaging on consumer health.
- There is a statistically significant gap in industrial safety practices during the manufacturing of food-grade plastics.
- There is a statistically significant contribution of food-grade plastic waste to environmental pollution in Saudi Arabia.
- There is a statistically significant correlation between public awareness and the safe handling and disposal of food-related plastics.

Scientific theory followed

The theory behind this scientific research is that of an interdisciplinary synthesis of the toxicology, environmental science, and industrial safety theory, which would achieve the aim of clarifying and controlling the health, safety and environmental (HSE) effects of food-related plastics. The precautionary principle is part and parcel of this approach expressing an idea that the measures must be taken to avoid adverse impacts on human health and the environment by taking into consideration possible scientific indeterminacy. This rule especially applies to assessing the food-grade plastic grade as more and more evidence points towards there being a possibility that plastic elements might leech dangerous materials in some circumstances.

The basis of migration theory in food contact material is one of the fundamental theory pillars in this research as it explains how the substances in food package may migrate into the food. Adly et al. (2025) offers an interesting case study in Saudi Arabia, where biologically important substances, polycyclic aromatic hydrocarbons (PAHs) and other substances were detected to change to plastic containers into food, particularly when heated. This is congruent with previous toxicological models which relate polymer degradation/additive release with thermal and mechanical stress. The contamination of these substances in food sources not only contravenes the food safety standards but also, creates long term health hazards to the people which hold the argument that all comprehensive approach of safety is needed in the systems of packaging.

Together with toxicological issues, environmental risk theory also offers a different perspective in determining the effect of the plastics. The linear production -consumption-disposal model that characterizes plastic use results into massive environmental degradation. There are high rates of contamination of the terrestrial and marine ecosystems, and this is caused by the lack of proper systematic disposal of plastic food packaging (Ugoeze et al., 2021). Their survey incorporates ecological theory with the models of the public health that demonstrates the build-up of microplastic in the environment and re-enters the human food chain, thus creating a loop of exposure. The result of such findings confirms the necessity of sustainable lifecycle management of plastic products.

Against this background, it is meaningful to bring circular economy theory to a position of valuable scientific foundation of the alternative problem solutions. By comparing the linear model with a new one (a circular model), Mazzi (2023) believes that it is necessary to switch

to the circular model that pays much attention to investing in waste minimization, increased efficiency of resources, and environmental safety at the design stage. The paper reveals the potentials of circular production patterns in the plastic sector in decreasing business risk and waste on the environment. Under the Saudi context, switching to this theoretical model implies the re-reviewing of the material selection, recyclability and post consumption routes of food-grade plastics, even within industrial regions such as Yorkbu.

To guarantee the full HSE assessment, this paper will equate the industrial safety concept as well, especially in the application of industrial safety theory to chemical exposure and working criteria. As Elete et al. (2024) observe, the HSE innovations introduced to an industry today, including the coating and packaging one, are more dependent on the risk assessment models combining both qualitative and quantitative indicators. This would not only lead to regulatory compliance but also predisposition of risks occasioned through the process. The adoption of these types of safety-oriented paradigms is also necessary in Saudi food packing industry where the fast industrialization has dictated increased HSE responsibility.

A further aspect of theoretical richness is provided by the green chemistry and materials science paradigm which speculates on substitutes to the existing compositions of plastic. Ikegwu et al. (2024) provide a perspective of green solvents applied in the recycling of multi-layer films by using a systems view. Their study points out the prospects of eco-friendly processes that do not alter the functional features of both materials and materials of packaging with such processes contributing to sustainability agendas. Likewise, Faraz et al. (2024) consider the application of organic nanomaterials in food packaging and find that the safety standards and regulatory framework should be renewed in order to keep up with the technological advancements. The analysis of innovation preparation in the Saudi industry and its correspondence to the safety practices on the global level are based on these theoretical inputs.

The theory of education, namely, knowledge transfer model of HSE also confirms the study as it pertains to the reconsideration between industry staff and consumers. NaInna et al. (2022) suggest the inclusion of HSE education as a part of the official training programs, particularly in developing economies. They have the model according to which active HSE culture minimizes the incidents and enhances the general environmental performance. According to this the application of similar training models in Saudi Arabia will be useful in

improving regulatory compliance and consumer safety with regard to the use and handling of food plastics.

The even greater support of this theoretical framework is the field of legislative theory that deals with the influence of institutional structures on the behavior within the industrial and consumer contexts. The authors of the given study, Hartmann and Johnson (2023), conduct a review of the legislation in place in manufacturing areas regarding HSE, where the law can impose safe measures and punish negligence of the environment. The analysis suggests that good legal framework is essential to harmonize the practice of the area with the international standards. This is especially applicable to Saudi Arabia which is gradually developing regulatory systems, and economic diversification as well as industry growth with the vision 2030.

Public health theory is also used in the research especially during exposure assessment and risk communication. In the article by Sattar (2023), the preventive strategies used by the battery industry to prevent exposure to lead were examined, and it may be deduced that an analogous interventionist model can be implemented in the environment of plastic packaging. The integration of engineering control measures, monitoring and community involvement therein create an integrated strategy which can be adopted to address the adverse effects of food packaging on the populace health.

The theory of material science also has an equal emphasis in the determination of the composition of plastics and their behavior. Khodyrieva (2025) studied extensively the additive content of polyethylene and the impact it has on health and the environment. This doctoral dissertation contributes to the view that the molecular nature of material properties is important in predicting interaction of materials with food and environmental agents. In a similar fashion, Akhtar et al. (2024) presented cellulose-based films as an alternative to plastic through providing biodegradable solutions of a similar functionality that also rests on the theory of polymer science.

The theory of innovation especially the technology adoption life cycle will be handy in evaluating the penetrability of new packages along with the environmentally friendly applications in the Saudi market. According to Abatan et al. (2024) in order to succeed, innovations in packaging should correspond to the goals of the industry, the expectations of the consumers, and the trends of the regulations. Diffusion of innovation theories aides in

determining the rate of technological change and the extent of its application particularly in fast moving consumer products (FMCG) whereby packaging is a major aspect.

Lastly the technical part of this research is grounded on food science and packaging theory. Back in 2020, Singla (2020) identified such primary safety issues in plastic food packaging as permeability, stability, and possible chemical reactions. These aspects affect design and material choice, which also justify the basis of strict tests and compliance standards.

To sum it up, the work is informed by a broad range of scientific theories that share the common denominator of critical assessment of health, safety, and environmental effects of food-grade plastics. These theoretical grounds encompassing such areas of focus as toxicology and material science, environmental risk and public health, allow exposing the Saudi food packaging industry through a multi-dimensional prism within which the industry can be assessed. The combination of these theories contributes not only to the increase of scientific visibility of the researched but also presents practicable ways of reform and innovation.

CHAPTER 2

Introduction

The recent huge dependence on the use of plastic materials in packed food and handling stems to the rising academic interest concerning their impact on health, safety and/or environmental concerns. The current literature review is set to examine and collate the available literature on issues of risks and challenges attached to the use of food-grade plastics as well as the regulations governing their use and relevance it has to the Saudi Arabian territory. Since food items that are prepared in plastics are used daily by most people, it is imperative to examine the direct as well as indirect effects of the chemical migration, the manufacturing process and wastage procedures.

This chapter is a survey to overviews studies that address the health risks that are caused by materials that leach out of the plastics into food and the impact that these leaches have on the environment after poor disposal and the occupational risks of the plastic manufacturing industry. It also shows the new discovery like sustainable packaging solutions and green material. This review gives an exhaustive background of the research topic since a wide selection of views and discoveries in the international and regional literatures was analyzed. Moreover, it determines the gaps that exist in knowledge and governance, which makes it necessary to target research in Saudi food and plastics industries, hence steering the course of the pending study.

Literature Review

The presence of the plastic materials in food packaging has become inseparable side of the contemporary food systems in terms of low costs, strength, and food quality preservation. All this, though, is at the cost of the growing dangers suspected to human health, long-run sustainability of the environment, as well as creating industrial safety standards. There is a rich network of scientific research on these risks that has shed light on the secret costs of plastic consumption particularly in regard to chemical migration, ecological pollution, workplaces security, and regulation loopholes. This review of the literature deals with the three aspects of health, safety, and environment (HSE) of the use of plastics in food, especially in global and Saudi Arabian settings in respect to the use of plastics in global dimensions, and challenges and innovations.

Migration of chemical compounds in plastics into food is one of the most burning problems found in the literature, which may be enhanced by heat, acidity, and long duration. Adly et al. (2025) analyzed the occurrence of this phenomenon in Saudi Arabia in terms of the presence of polycyclic aromatic hydrocarbons (PAHs) and other substances leaching into food-grade plastics. Their conclusion was such that even the safe forms of plastics when subjected to normal circumstances they may produce toxic materials and hence causing major endocrine disruption and carcinogenic effects. This finding implies the shortcomings of the existing food safety evaluations, which might be incomplete, not covering the effects of low-level chemical residue exposure in the long-term. The same issues are reflected by Khajavi et al. (2019), and the author draws attention to the fact that nanoparticles and other additives that manufacturers employ to manufacture plastic substances are likely to enter food and beverages due to a gradual leakage process, leading to bioaccumulation and physiological problems.

Chemical leaching is not the only health implication. Singla (2020) states that all types of plastics, such as polyethylene and polyvinyl chloride, can decay by time, particularly, when they are at high temperatures or under UV rays. Such deterioration can trigger the spread of microplastics that not only occupy food sources but can pass the customary digestive services and accrue in human organs. Khodyrieva (2025) also contributed to this idea with her doctorate dissertation on the composition of plastics and the impact on health, which denoted that such additives of plastic as plasticizers and stabilizers, in most cases, do not undergo long-term studies of safety due to market demand. Therefore, one can accidentally consume

harmful substances with plastic containers and packaging, which sometimes contain toxic substances.

The literature also talks about plastic usage especially in food applications as well as its negative effect on the environment in addition to its health implications. Ugoeze et al. (2021) gave an in-depth examination of the ecological impact of plastic waste or rather the food and healthcare waste. The research found that the problem of plastic pollution is chronically active because it technically causes erosion of the soil, pollution of the sea, and the violation of the natural food chain. The authors pointed out that developing nations potentially experience extreme conditions in dealing with plastic waste because of poor infrastructure and control. These issues can effectively be applied to the fast urbanizing areas across the Middle East such as Saudi Arabia where food service and retail use single-use plastics. Brey (2025) also revolved around environmental management within the plastics industry, and they noted that, although circular economy systems are becoming quite popular in Europe, they have not been effectively implemented elsewhere because of the economic and logistic challenges they present.

Circular production models are a viable solution that offers a way forward that hopes to seal the end of plastic waste by way of recycling, reusing, and biodegradable options. Even though Mazzi (2023) carried out a case study of an industry (fashion), they provided transferable conclusions related to plastic processing in food packaging. The article presented a model of assessment of environmental and safety risks in construction and is based on the lifecycle analysis (LCA), energy consumption, and occupational safety. The author argued that sustainable circular production can significantly reduce the environmental footprint of plastics if adopted alongside strict HSE protocols. In food systems, this translates into selecting materials that are both functional and recyclable, supported by infrastructure for sorting, processing, and reuse.

In the aspect of safety, manufacture and processing of plastics products also poses a danger to workers and occupationally, particularly in the developing or fast-industrializing nations. Elele et al. (2024) accentuated the significance of active HSE innovations in the coating and packaging industries. They found out in their study that most industrial sectors do not have proper risk assessment structures, and mostly these expose them to detrimental chemicals, poor ventilation, and physical injuries. On the same note, Sattar (2023) explored the case of HSE in the Pakistani battery manufacture business venture and identified the similarity of

emerging regulatory gaps and inadequate training that might be replicated in plastic production industries. These results reinforce the argument on the necessity of a strong culture of HSE working in a manufacturing setting, which goes beyond mere compliance to encompass worker educations, engineering controls, and emergency preparations.

The role of HSE knowledge dissemination is expressed by Na Inna et al., (2022), who delivered the call to introduce into higher institutions the study of HSE. Their suggestion is based on the fact that the establishment of a safety culture starts with training, especially in the fields of technology and industry. It is in line with the demands of the Saudi plastic sector, which requires numerous frontline employees who might not have undergone an official education in chemical safety or environmental conservation. Incorporation of HSE modules in technical training will help to increase the level of compliance with national and international standards which in the long term would help in bettering the workplace environments and safety of products produced.

The regulatory mechanisms and legislative controls also act as the primary way of reducing the risk of plastic utilization in food systems. A brief description of the best practices in the enforcement of regulations by the HSE, third-party auditing, and safety certification was provided by Hartmann and Johnson (2023) in their comprehensive insight into the laws concerning HSE in the manufacturing industry. Their experiences are especially helpful in an environment where regulators have yet to develop or routinely exercise their mechanisms. Trybula et al. (2018) also indicate the necessity of custom legislation. who studied the legal issues of nanotechnology packaging, which means that innovation seems to follow legislation. The development of the similarities between the local legislation and international standards (like EU or FDA) can be a key to guaranteeing the increased level of safety of food-grade plastics in Saudi Arabia.

The future of food packaging in the literature is dominated by the themes of innovations in technology and environmentally friendly alternatives. Ikegwu et al. (2024) analyzed the challenge of using green solvents in the separation of multilayered plastic films that are typically found in food packaging; however, because they have many layers, they are very challenging to recycle. In their study, they were able to illustrate that innovation at the system level would be able to enhance recycling levels and still retain the original character of the packaging materials. Similarly, Akhtar et al. (2024) examined the possibility of the use of

cellulosic films as biodegradable films replacing the plastic film. The alternatives are all renewable sourced plant-derivation, have similar barriers and could help minimize the reliance on petroleum-derived plastics when widely used.

An additional complex occurs when nanomaterials are used in food packaging. Faraz et al. (2024) have outlined the two-part nature of organic nanomaterials that produce a superior shelf life and antimicrobial effects but increase concern regarding consumer safety and the chemical degradation of the environment. Such concerns were reflected in the publication produced by Trybula et al. (2018), who believed that regulatory and risk assessment models should change alongside technology. All these works emphasize the significance of juggling between innovation and responsibility, which is that new materials should be tested accordingly, whether they pass both their performance and safety tests, before being introduced on a large scale.

Considering the fast-moving consumer goods (FMCG) industry, Abatan et al. (2024) studied the effect of sustainable packaging innovations on HSE practices. They did find out that consumers are progressively turning towards environmentally friendly products and this forces companies to use more environmental friendly materials and increase transparency. Such a transformation is more than an adaptation to the environmental demands, as it is also a calculated bet on brand loyalty within growing markets that are getting more environmentally aware. For Saudi Arabia's growing FMCG sector, this represents an opportunity to lead the region in sustainable packaging reforms.

The other challenging issue evident in the literature is the fact that there is no consumer awareness of the proper means of disposing and using plastics applied to food. As pointed out by Oppong (2014), no matter how high the quality of a regulatory or technological solution, it will not be able to reach its objectives without proper public health communication. Consumers in most areas in the world do not know about the health problems that can arise out of the reuse of some plastic containers or the careless disposal of the same. Educational campaigns, labels and community activities thus form a very important part of a comprehensive HSE strategy.

Connectedness of health, safety and environmental aspects is also reflected in the literature reviewed, with the range of consequences on one aspect in response to intervention on another aspect being a kind of reflected effect. As an example, workplace safety initiatives such as enhancement of workplace ventilation or improvement of the maintenance of the

equipment can indirectly decrease the emissions and increase the quality of a product. On the same note, the current use of biodegradable packaging would reduce the amount of waste and increase the safety of the consumers through the prevention of chemical leaching. When writing about pesticides, Matthews (2015) stated that effective HSE strategies should pursue a systems thinking perspective, and that it is impossible to treat risks as isolated entities; instead, they are to be treated as individual links in a chain pointing to a social, technical, and environmental web.

Overall, the literature indicates a solid evidence base concerning current knowledge on the HSE implication of plastic use in food systems. Academics have explored an expansive range of topics- including chemical migration, occupational safety, legislative systems and material novelty. Yet, there are great areas of deficiency, especially when region-specific studies related to the Gulf region and Saudi Arabia are in focus. Although global research is beneficial, it is necessary to consider pluralistic aspects by doing local evaluation to factor in cultural, environmental, and industrial variations. With Saudi Arabia still in the process of industrializing and modernizing its food systems as part of the Vision 2030 process, highly focused research studies, policy-making, and industry transformation on the topic of food-grade plastic dangers and how to make food systems healthier and more sustainable in the future have become dire needs.

Commentary on Previous Studies and Research Gap

The literature found identifies a thorough perception of the varied effects of plastic use in food systems, and immense contributions have been provided in the fields of chemical safety, environmental sustainability, industrial health and safety, and technological innovation. All these studies generate the fact that there are complicated and sometimes neglected risks of using plastics on a large scale in food packaging and handling. Nevertheless, regardless of the wealth of the current research, a number of critical gaps and shortages should be noted when analyzing it more closely, specifically, within the domain of region-specific documentation, practical application, and combined HSE strategies.

The significant advantage of the literature is that it has determined and measured health risks, which is connected to plastic packaging. As a case in point, there is a substantial empirical evidence by Adly et al. (2025) and Khajavi et al. (2019) in the migration of chemicals in the food through the plastics; stressing on the health risk of chemicals like PAHs and additives. However, such studies usually deal with laboratory-based interventions or an artificial

environment and there is a lack of field-based studies that evaluate the actual exposure in various population groups to be tested, particularly in the Middle East countries. Moreover, in the majority of them the different consumer behaviors that may vary drastically and create a distinct effect (reheating of food in plastic containers) are not distinguished.

Environmentally, researchers like Ugoeze et al. (2021) and Brey (2025) have outlined the ecology effects of plastic waste, citing marine pollution, microplastic contamination, and ineffective waste management as the major issues. Even though these pieces of writing are useful in providing international insights, a clear gap can be noted when it comes to the approach and literature discussing the distinct arrangements of Saudi Arabia in terms of waste management and environmental regulations. Due to the unique environmental characteristics of the country (i.e., nature of extreme heat and dry ecosystems), the effects of plastics and their interaction with such parameters should be studied at the local level and the research is needed to understand to which extent the existing waste management schemes (especially the aspects of their suboptimal efficiency) stimulate or eliminate the issue.

The concept of occupational health and safety in the context of plastic manufacturing has been extensively covered in the works such as Elete et al. (2024) and Sattar (2023), as the authors identify the presence of the safety gaps in the industrial practices and the necessity of integration of the HSE concept. The manufacturing settings, however, considered in these studies are mostly based on South Asia and Africa whereas not much attention has been paid to the industrial regions of the Gulf. Saudi Arabia being home to the giant petrochemical and plastic manufacturing centers in places such as Yanbu and Jubail does not have specific case studies that evaluate the sufficiency of HSE standards in local plastic manufacturing plants. This factor is one of the research gaps that inhibit the creation of specific measures to defend workers and improve the safety of production in the Kingdom.

In the area of lawmaking and education, Hartmann and Johnson (2023) and others, (2022) can help to understand the significance of effective regulatory policies and the spread of knowledge. Although this is the case, little has been done on whether the current Saudi HSE regulations in place are implemented as well as whether the regulations are effective especially when they are applied to food-grade plastics. The evaluations of the compatibility of national policies to international standards of safety like OSHA or the FDA are not systematically evaluated and a gap exists in the importation of knowledge of regulatory compliance and institutional preparedness in the region.

Regarding sustainable innovation, research advances such as Ikegwu et al. (2024), Akhtar et al. (2024) and Faraz et al. (2024) hold promising progress in the field of biodegradable alternatives and nanotechnology in food packaging. These technological solutions imply some possible ways of how the health and environmental burden of plastics could be reduced. However, literature fails to study the penetration in such technologies in the food industry in Saudi Arabia. Such factors as prices, policy incentives, and consumer acceptability that are the key to the successful adoption are rarely at issue in regional contexts, and it is not clear whether such solutions are practically viable or applicable in the local market or not.

Besides, though certain literature, e.g. Abatan et al. (2024) and Oppong (2014), references the topic of consumer awareness and corporate behavior, the overall evaluation of the image and attitude in Saudi Arabia is not offered. The levels of cultural practices, awareness, and disposal habits are critical factors, which determine the effectiveness of HSE policies in addition to its practicality. The lack of such data may result in policies and interventions that are erroneously designed to completely miss the timbre of what is happening and what is necessary on the ground.

This commentary defines the main research gap that should be filled by the present study, based on the fact that there is a gap in terms of localized, integrated investigation of the HSE dimensions of food-grade plastics in Saudi Arabia. Globally conducted studies can be beneficial in their structures, as well as their information, but unless regionalized, they become inapplicable to the bulk of the people. This study aims at filling in that gap by specializing on the case of Saudi Arabia and examining the local conditions of industrialization, of the environment, of the effects on health related to food related plastic use, and of the behavior that is a part of the framework of it.

The research will also focus on questioning the extent of Saudi plastic industry being in accordance with the international HSE regulations, whether regulations are being followed effectively and whether the local industry is prepared to accept the safer and more sustainable modes. By doing this, it will cooperate to add knowledge not just academically but also practically on policymaking by presenting evidence-based suggestions to fulfill the needs and conditions of the Kingdom.

Theoretical framework

Introduction

Purpose of the Theoretical Framework

Theoretical structures act as the intellectual road map to any intellectual inquiry by informing the researcher along the concept, analytic, and interpretive phases of the simulation. To conduct an analysis of the health, safety, and environmental (HSE) of plastics in food application in Saudi Arabia, the theory will form the basis of delving into the various aspects of plastic use, risk exposure, and some regulatory approaches as well as the dimensions of sustainability. Through this it offers a framework of connecting the theory and practical aspects of chemical mobility due to food packaging food, working safety and environmental influence. The framework is a kind of mixed combination of toxicological theory, scenario of environmental risks, aspects of HSE management, and materials science. The theoretical lenses allow us to view the implications of the use of plastics, especially in food systems, holistically, and precondition the approach of methodological and analytical construction of the study.

The framework is crucial in framing the research problem in a scientific paradigm which does not only recognize the possible hazards but also looks at their mechanisms, distribution and prevention means. Theory provides the study with predictive power and ability to extrapolate findings to non-specific situations. In a fast industrializing country such as Saudi Arabia where production and use of plastics are increasing at a similar rate as the modernization process in the country, sound theory is essential in providing guidance to the regulation, modernization of the industry, and population health policies.

Health, Safety, and Environment (HSE): Conceptual Foundations

Definition and Scope of HSE

Health, Safety, and Environment (HSE) is a collective system that characterizes policies, procedures, and practices that have an objective of protecting human integrity and ecological integrity of both industrial as well as consumer parameters. Health is the absence of conditions that may cause diseases or injuries especially due to requirements of chemical, biological or physical threats. Safety deals with the prevention of accidents and injuries particularly within the workplace whereas Environment deals with the minimization of the adverse effects relating to the air, water, soil, and biodiversity. The HSE framework becomes

a very important perspective using which to evaluate product safety, their production processes, and their final discard in the context of plastics utilized in food.

Elete et al. (2024) explain that the adoption of HSE standards within industrial operations would drastically minimize the risk of operation, as well as enhance compliances with the international standards. But HSE is not just like the compulsory requirement but is a philosophical motivation towards sustainable and ethical behavior. HSE in this research is a value-added dimension which brings human health, worker safety and environment stewardship into singularity in appraisal of plastic food packaging.

Development of HSE in industrial sectors

HSE practices have changed due to past accidents, legislative changes and scientific innovation. The HSE frameworks were initially developed in the heavy industry like oil and gas firms, but it has shifted to manufacturing, food product production and even consumer goods. Safety and environmental responsibility have been institutionalized in all sectors through the emergence of global norms like OSHA (Occupational Safety and Health Administration), ISO 14001 (Environmental Management) and HACCP (Hazard Analysis and Critical Control Points).

The lack of chemical simplicity of polymers and high-processes risk environments where they are manufactured have made it necessary to employ the use of HSE in the plastics industry. Unlike other industries that have not inculcated HSE in their operations, such a move is not only punishable by law (Mazzi 2023). but also reputational damage and long-term sustainability challenges. The emphasis is now shifting toward proactive risk assessment, continuous monitoring, and integration of environmental considerations throughout the product lifecycle.

HSE in-Context of Food-Grade Plastic

Plastics in food-grade communications are particularly noxious in terms of HSE to the fact that they come into direct contact with consumables, and chemical compositions are complicated to follow. Such plastics usually have additives like plasticizers, stabilizers and flame retardants which migrate into food in special circumstances. Such migration has serious health implications that impose the risk of carcinogenic effects, as well as hormonal imbalances. In their latest study, Adly et al. (2025) report Saudi Arabia-based investigation, which has revealed the presence of PAHs and other harmful substances in food samples that

have been stored in plastic containers, therefore indicating the lack of safety among consumers and the regulation.

Safety wise, employees dealing with the manufacture of food grade plastics, are prone to a number of dangers such as exposure to bad smells, injuries upon collision with the machines, and skin scrapes because of chemicals. These dangers highlight the need to ensure industrial safety measures, good training and protective devices.

Food grade plastics manifest an impressive contribution to environmental pollution through the process of single use and non-biodegradability. Ugoeze et al. (2021) point out that plastic packaging makes a significant portion of municipal solid waste, most of which is discarded in landfills or water bodies. Soil pollution, destruction of marine ecosystems, and the generation of microplastic- pollutants are considered the environmental consequences of this form of waste, which also rejoins the food chain and adds additional problems to the complications of health outcomes.

Saudi Arabia Industry Applicability

Saudi Arabia has a rather peculiar industrial and environmental situation that can be observed to study the HSE of food-grade plastics. The nation boasts a vast petrochemical sector and it has experienced its plastic production capacity to flourish at high levels especially in locations such as Yanbu and Jubail. The amount of plastic products produced by these industrial zones to both local and global economies is high. Nevertheless, the regulatory environment of HSE is still maturing in Saudi Arabia, and patchy enforcement may exist in various parts of the country.

According to Elele et al. (2024), there is an urgent need to instill HSE as a part of the national policy and industrial strategy in such emerging economies. According to the research carried out by Adly et al. (2025), there is a possibility that a lack of regulation of plastic products used as food storage and packaging systems has already put Saudi consumers at risk. These risks are further aggravated by the absence of mass HSE training and education, which is why special measures and education activities are required.

Toxicological Theory and Chemical Migration

Fundamentals of Toxicological Risk Assessment

The science of undesired effects of chemical, physical, or biological agents on living creatures is called toxicology. At the center of toxicological theory is the notion of dose-response, the idea being that the most profound the health effect requires an equivalent relationship between exposure intensity and exposure duration to a toxicant. Toxicological risk assessment is used in the case of food-grade plastics to measure the probability and seriousness of injuries caused by intake of chemicals that are released during storage using food packaging materials.

The risk assessment is a process that usually follows four steps: hazard identification, dose-response assessment, exposure assessment and risk characterization. Through these, scientists and regulators are able to identify a safe dose of exposure and come up with guidelines in manufacturing and use. New materials like nanocomposites and bioplastics make it difficult to use the traditional designs of toxicology which demand new frameworks that consider particle size, bioavailability, and new interaction pathways as they are highlighted by Faraz et al. 2024.

Chemical Migration Food Packaging Theories

Chemical migration refers to the transfer between packaging materials to food content. The following factors control the phenomenon i.e. temperature, time of contact, the type of food (acidic e.g., fat content), type of the packaging material and its physicochemical properties. Migration theories are based on diffusion and partitioning model describing movements of molecules within material boundaries and their absorption in food matrices.

Adly et al. (2025) endorsed these models with facts by examining the PAHs in food maintained in plastic containers in Saudi Arabia. They obtained their findings like storage temperature and time had a great impact in the level of migration, and higher temperatures increased the rate of chemical leaching. These conclusions strengthen the necessity in the strict instructions of storing and managing food-grade plastics.

Models of Bioaccumulation and Human Exposure

Bioaccumulation is an accumulation process whereby contaminants within a given organism accumulate over a time. This accumulation is usually of such substances as toxic chemicals

in organisms. In toxicology human exposure models incorporate aspects of route of entry (oral, dermal, inhalation), frequency of exposure, and susceptibilities. When it is used on plastic package materials, these models are useful in forecasting adverse health effects of using the same containers repeatedly, particularly when heated or stored during a considerable length of time.

Ikegwu et al. (2024) specify that the newer materials on packaging have to be assessed in terms of their ability to add to cumulative exposure in humans. This is in addition to known toxins, in addition to degradation byproducts and secondary pollutants potentially formed during recycling of plastics or burning.

How to apply the Theory of Toxicology to Food Plastics

Evidence-based policy and consumer protection requires integration of the toxicological theory in the course of assessing food plastics. The regulatory authorities tend to use toxicological data to set the limit of migration, approve substances for food contact and recall products where the influence exceeds the limit of safety. Nevertheless, testing outdated methods might not allow determining the efficacy of new substances: nano plastics or bio-based compositions (Faraz et al., 2024).

The present study uses the theory of toxicology to assess the suitability of the existing standards in Saudi Arabia, as to whether Saudi products correspond to global standards. It also notes the necessity to continue monitoring, more complex testing scheme, and educating population about the threat of the improper use of plastic.

Environmental Risk and Pollution Theories

Linear vs. Circular Economy Models

The linear and circular economy framework as the contrast stands out as one of the dominating theoretical prisms regarding the environmental impact of plastic use consideration. Linear model has a simple trend that is extract, produce, consume, and dispose. The methodology has been the foundation of the entire worldwide plastic industry even as far as food-grade plastics which are mostly and ideally single-use, and non-biodegradable. An immense pile-up of plastic wastes in disposal sites and oceans, as well as Earth-based ecosystems is the result of this linearity.

The circular economy model, on the other hand, aims at redesigning this flow by encouraging resource productivity, material recovery, reuse and recycling. The circular economy model has attracted interest in all parts of the world which shows a new approach to the ecological burden of plastics, which Brey (2025) records in his case study of the automotive industry. Brey underlines that going circular implies changes to the system, such as product design, consumer culture, and legislature. The circular model can be applied to the food packaging industry to promote recycling materials, bio compostable films, and closed loop supply chains.

The shift towards a circular economy in the furnishing of plastics is a necessary environmental initiative and a strategic chance in the case of Saudi Arabia. Since the country consumes more plastic and produces more waste, especially in its cities, implementing the circular way of production (long-term producer responsibility (EPR), eco-design, and recycling with the participation of both the state and business would aid the sustainability of food-grade plastics in the country and relieve its environmental burden.

Pathways of the Plastic Waste and Environmental Degradation

There are several routes to environmental degradation by plastics: direct litter and landfilling, and ocean and groundwater pollution through chemical leaks. When it comes to food it is over nurtured expression especially in food applications where the food is put in a plastic container and the food may not be sealed in it; the food in a way is simply discarded once it is taken out of the container. That is when the cost to the environment is disproportionately higher because the container is not being used beyond that point.

Khodyrieva (2025) characterizes how the most widely used plastic in food manufacturing polyethylene does not naturally decompose and may remain in the environment up to hundreds of years. These plastics degrade when subjected to sun and mechanical forces and the resulting micro- and nano- particles poison water bodies, land and even air. The properties of such microplastics are dangerous to biodiversity since they are consumed by animals, pass through the food chains, and eventually go back to people.

In addition, burning plastic wastes, more common in areas with little landfill or recycling facilities, emits toxic gases and dust. These are dioxins and furans which are known carcinogens and volatile organic compounds (VOCs) which form air pollution. These risks are increased when disposable plastics are not discarded properly as in urban and semi-urban areas in Saudi, where food services largely depend on plastics.

Although there has been increased awareness, Brey (2025) observes that most industrialized economies find it difficult to have an effective system of segregation and recycling of wastes. The difficulty is exacerbated in developmental situations, where community education, infrastructure and rule assimilation are held up. To reduce the environmental harm due to plastic food wrapping, Saudi Arabia has to invest upstream (design of product and material selection) and downstream (waste collection and processing) solutions.

Theory of Microplastic Pollution and Ecological Risk

The ecological risk theory aims to appreciate the effects of pollutants on the ecosystem, including microplastics, at several levels in a manner that has implications ranging to molecular/cellular effects, effects on species survival and services offered by the ecosystem. The endless lists of pollution threats have been replenished with microplastics, which are fragments of plastics smaller than 5 mm in diameter, whose size can be listed as one of the most sneaky forms of pollution, specifically in the case of packaging plastic that disintegrates after the consumption of the product designed to be used in single use.

The potential of microplastics described by Khodyrieva (2025) to adsorb other pollutants, such as heavy metals and POPs, is alarming because it makes this type of pollution serve as vectors assisting the transfer of toxins across the ecological systems. Planktons, fish, birds are exposed to these particles, whereby, the particles cause internal injuries, imbalance of hormones as well as reproduction behavior changes. Microplastic contamination has become one of the major variables in ecological risk assessment to establish the health of the ecosystem.

Along the coasts of the lands of Saudis such as Red Sea and the Arabian Gulf, sea creatures already face pressure in terms of shipping, industrial effluent and devastation of the habitat. The plastic waste-generated pollution may be capable of tipping-over the weak ecological systems. Using the ecological risk theory in the context of Saudi Arabia will give a predictive use of the more severe outcome of the plastic waste and evidence-based policymaking in terms of marine conservation and plastic waste management.

Lifecycle assessment and Sustainability Models

In the assessment of the environmental impact of products throughout its life, in detail such lifecycle assessment (LCA) models are essential. LCA is congruent with the theory of

sustainability, focused on the idea of satisfying present demands with no effects on the failure of future generations to do the same to their needs.

Brey (2025) uses LCA models when he assesses the circular practices of industrial sectors, stating that LCA makes an intervention in the product chain, as it can determine environmental hotspots where improvements should have the greatest effect. With regards to the food-grade plastics, LCAs show that the plastics may in many cases consume less energy to manufacture as compared to the other alternatives in the market such as glass and metal, but at this disposal stage, due to its poor biodegradability and a limited recycle capacity, the impact of its presence may be felt strongly.

In the case of Saudi Arabia, an implementation of LCA models may influence a more sustainable choice of materials by the government and industry and a more sustainable policy design. These models may be used as a guide on product labeling systems, procurement policies and recycling requirements. enabling a data-driven transition toward environmental accountability in the plastic sector.

Occupational Health and Industrial Safety Theory

Risk Management Theory in Manufacturing

Risk management theory in manufactures describes the process of identification, assessment and control over the risks that may constitute damage to employees, property or environment. The hazards involved in the manufacturing of plastics (particularly those used in food) are the exposure to chemicals, physical injuries, accidents involving equipment, and ergonomic are being strained. Assessing the hazards and putting in place controls on operations has well-structured frameworks like the ISO 45001.

Hartmann and Johnson (2023) emphasis that risk management should be proactive not reactive, and it should deal with prevention, including training, maintenance and monitoring. Such frameworks, though, are not merely protecting the health of workers, but also the quality and regulations in high-stakes production settings, such as those present in Saudi Arabia across its industrial cities.

The contribution of risk management theory in this work justifies the study of the practice at the workplace, reveals the loopholes in the safety precautions, and provides the recommendation to be applied in consultation with international standards. It also correlates

safety of workers with the safety of products improperly managed facilities will have increased chances of manufacturing polluted or non-compliant food grade plastics.

Models of Safety Culture and Behavioral Safety

Although technical barriers are needed, human attitude is at the forefront in ensuring health and safety at the workplace. Behavioral models of safety and a concept of the so-called safety culture accents, that the right attitude of the workforce to safety, their values and perceptions of safety impacts largely on the organizational performance. An effective safety culture is one that involves every employee right up to top management level, factory workers and everyone places safety on priority, report hazards without any fear of punishment and this is done on a regular basis.

A strong argument can be presented in the Pakistani battery industry, as summarized by Sattar (2023), whose safety culture allowed minimizing the exposure to lead and increased the compliance level. He shows that the engagement in safety performance can occur not only in the process of regulation activity but also in the process of leadership participation, communication, and worker empowerments.

When these insights are applied into the context of the manufacture of plastics in Saudi, it becomes possible to outline some of the areas of opportunity. Most of the facilities in the region struggle to develop a culture of safety despite its strong infrastructure and investments. Using the behavioral safety theory, this research recommends the use of leadership training and awareness programs and incentive systems that should include safety in the DNA of organizations.

Regulations and ISO/OSHA Requirements

Regulatory compliance benchmarks exist in the forms of international standards, including OSHA, environmental management (ISO 14001) and occupational health and safety management (ISO 45001). These standards provide systematic steps of dealing with hazard identification, performance tracking, training and improvement. According to the argument proposed by Hartmann and Johnson (2023), because compliance with such structures only introduces a minimum amount of safety, the true development happens when organizations embody such regulations and make them part of daily activities.

International HSE standards, in Saudi Arabia, is one of the factors to be met by any company, which aims at establishing business in industrial cities or exporting products to other countries around the world. Nonetheless, the presence of enforcement and institutional capacity is not spread evenly. As used by NaInna et al. (2022), regulatory compliance should be in a conjunctive relation with education and cultural change to have a long-term benefit. Their experiences in Nigeria show that legal frameworks are not enough without any training and establishment of institutions.

The theoretical perspective justifies the research purpose of determining the compliance of the Saudi plastic manufacturers to international safety standards. It also strengthens the importance of capacity building of the inspectors, policymakers, and plant managers so as to improve on compliance and comprehension of HSE standards.

Implementation to Saudi plastic manufacturing centers

The Saudi scenario therefore shows mixed results when the occupational safety theory is applied. On the one hand, the nation has well-developed manufacturing regions where there was an access to foreign consultants, technologies, and funding. Conversely, the workforce diversity, a lack of training initiatives, and policy inconsistency represent the factors that suppress the ideal outcomes related to safety.

NaInna et al. (2022) suggest that the practice of HSE education should be institutionalized and apply to every level of education or resorting to vocational training and up to executive management. To plastic companies this would mean extensive induction programs, lifelong learning and collaboration with academic and regulatory organization. Furthermore, Sattar (2023) stresses that actual data collection (e.g., incident reports, near-miss logs) plays an essential role in the decision-making process and adaptive safety strategies.

By integrating the theory of risk management, behavioral models, and compliance practitioners into the operational practice, Saudi plastic manufacturers will have the opportunity not only to protect workers but also guarantee that their products can comply with the international standards of food safety. It is imperative to do so because the Kingdom is aiming to be an international center of articulation of petrochemicals as well as plastics.

Regulatory and Legislative Theories

Policy and regulatory framework theory Public

Regulatory framework theory and public policy explore how governments and institutions develop, establish and enforce regulations in defending the interest of the people. These policies are significant in the case of plastic being used in food packaging to protect the health, safety and the sustainability of the population and the environment. The regulatory theory deals with the principles of legislation as a deterrence mechanism to regulate the behavior of the industry and as the remedy from time to time.

Explication of efficient regulatory rules on food-grade plastic would normally consider chemical protection quantifies, production privileges, tacking necessities, and diversion of wastes. According to Singla (2020), although regulations that govern the use of plastics have been created in many countries, very little is being done practically to enforce them. Effective policy framework should be scientific, economically viable as well as socially acceptable. Developing area such as Saudi Arabia, whose food is consumed in large volume using plastic packaging and where industry appears to be gaining momentum; it is necessary to come up with thorough and situationally appropriate policy.

This theory is relevant because it explains how the systemic risks are either controlled or overlooked by the regulatory authority. In the Saudi Arabian context, existing policies governing plastic use in food applications often lag behind technological advances and growing health concerns. Thus, this research adopts regulatory theory to assess policy gaps and propose a more integrated approach to HSE regulation.

Compliance and Enforcement theories

The compliance and enforcement theories are in-depth examinations of the rationale behind the action and inactions of various industries and individuals to the regulatory standards. According to these theories, compliance is not determined by legal compulsions alone; but there is perceived legitimacy, practicality and value of the rules under enforcement.

Responsive regulation model is one of the existing methods in this field that suggests striking the balance between punishment and persuasion. It is seldom enough when done through enforcement alone and frequently through penalties. Rather than, it can be advantageous to offer incentives to compliances, technical assistance and obtain public recognition of good practices, which is highly effective.

Consumer pressure, export regulation and brand image often encourages or rather dictates the compliance process in the food packaging industries. Abatan et al. (2024) also comment on the fact that sustainability approaches in the FMCG sector are gradually being employed not only on the basis of legal compliance but also because of market expectations. Firms, which do not conform to the changing environmental and safety requirements, will lose competitive edge.

In Saudi Arabia, there is a lack of unity in the law enforcement mechanism, particularly in the field of municipal waste and industrial compliances. The paper uses enforcement theory to point at the necessity of capacity building of institutions, inter-agency cooperation, and more intelligent enforcement, including digital tracking, public reporting platform, and transparent certification measures.

Regulatory Comparisons (EU, USA, KSA)

The dissimilarity between the models of regulation in the European Union, United States and Saudi Arabia demonstrates the variety of regulatory policies concerning the use of plastics in food systems. The EU, on the other hand, takes a precautionary approach, which implies that it stresses the tight regulation of chemicals in food-contact items via the extensive legislation such as Regulation (EU) No. 10/2011. This rule provides regulation of allowed materials, migration level and documentation of conformity evidence, which forms a science based policy culture.

FDA and other agencies of the United States use a more risk-based model. It sets acceptable daily intakes (ADIs) of chemical migrants, and requires forms of pre- market notifications on new materials. Although it is strong, the system occasionally lacks to make judgments of new materials (nano plastics or biodegradable composites).

In comparison, regulatory environment in Saudi Arabia is developing. Although general standards on plastic materials have been issued by such organizations as the Saudi Food and Drug Authority (SFDA) and the Saudi Standards, Metrology and Quality Organization (SASO), there has been no harmonized and transparent system on par with the EU or FDA. This loophole discourages accountability in the industry and faith of people.

This study uses a comparative regulatory theory to compare the Saudi policies with the international standards to determine good policies and policy tools that can be imported and made domestic.

Gaps in the Law and Problems of Institutions

Unfortunately, in the management of food-grade plastics, there are still large gaps in legislation and institutional arrangements despite international awareness. They are vagueness in the definition of the safe plastic substances, lack of complete migration limits, inadequate regimes of inspection, and a poor inter-agency coordination.

However, according to Singla (2020), highly developed legislative systems do not mean enforcement in the other countries could be supported by sufficient surveillance infrastructure, adequately trained personnel, and political or economical obstacles. The problems are compounded in emerging economies whose policy capacity is still in its infancy.

These problems have various implications in Saudi Arabia. To begin with, there are few accesses to public databases of the health and safety incidents regarding plastics. Second, some coordination among the environmental, industrial, and health agencies is irregular. Thirdly, there is little consumer education and participation by the civil society in policy design.

This conceptual framework lends credence to the argument that legal changes are not only inadequate; an equally important component of this is institution strengthening; stakeholder involvement and the continuity of the political will. This study can establish the basis of making policy recommendations that would be not only legally tenable but also practically feasible by adopting a legal and institutional theory.

Innovation and Green Technology Adoption

Innovation Diffusion Theory (Everett Rogers)

According to the Innovation Diffusion Theory (IDT) created by Everett Rogers, new technologies are spread between cultures at certain rate with distinctive reason and manner. The theory classifies adopters into innovators, early adopters, early majority, late majority and laggards, which are all dependent on perceived attributes of innovation (i.e. relative advantage, compatibility, complexity, trialability and observability).

With regard to food-grade plastics, the innovation diffusion plays an imperative role in adopting the practices of sustainable, such as compostable bioplastics, nanotechnology-improved packaging, and smart tracking labels. As discussed by Abatan et al. (2024), in relation to green packaging in the FMCG industry, its implementation largely relies on the market preparedness and institutional facilitation.

Regulatory delays, consumer unawareness and initial costs can be possible deterrents to diffusion in Saudi Arabia. When IDT is applied, the present study can determine where Saudi food packaging sector lies on the adoption curve, where obstacles in it are located, and what factors can be used to spur the diffusing process faster.

Model of Technology Acceptance (TAM)

Technology Acceptance Model (TAM) narrows down on the behavior of an individual as a complement to diffusion theory. It suggests that technology adoption is majorly prognosticated by perceived usefulness and ease of use. Such perceptions in the case of packaging will determine whether manufacturers will switch to using environment friendly packaging mediums and whether consumers are ready to embrace issues such as biodegradable packaging containers or the way to adopt recycling.

The researchers Akhtar et al. (2024) dedicated their efforts to highlighting the role of functionality and familiarity in the attitude of consumers to cellulosic films. When new materials are too alien or more ineffective, they can be abandoned. Equally, manufacturers are unfavorable to embrace innovations that may interfere with their production lines and those that increase their expenses without obvious repaid benefits.

One way TAM can be incorporated in Saudi Arabia is to realize psychological and logistical obstacles to the implementation of green packing technologies and design intervention, pilot programs, government subsidies, and awareness programs to address them.

Eco-Design principles and Green Chemistry

The principles of green chemistry endorse the establishment of processes and products that greatly reduce the production of harmful materials. This in the case of packaging includes the use of renewable materials, a reduction in the use of additives, better recyclability, and a decrease in lifecycle emissions.

Khajavi et al. (2019) comment on the possibilities of using nanoparticles in packaging that will allow minimizing their chemical migration and prolonging shelf life. The solutions are promising, but they should also comply with the food safety and regulatory requirements. Another related concept is eco-design, which embodies thinking in holistic terms, that is, thinking in terms of the attributions of a product, the way it is manufactured, the way it is used, and the way it is discarded.

The eco-design concept presents a solution in the industrial vision of Saudi Arabia to provide an avenue to reconcile economic diversity and environmental guardianship. Using green chemistry and eco-design theory, this study attempts to determine the gaps between the existing industry practice and international standards in sustainability and the ways in which innovation policy can wipe out the gaps that exist.

Smart and Biodegradable Packaging

Smart packaging and biodegradable packaging is on the cutting edge of green innovations. These technologies entail biodegradable materials, temperature responsive and pH packaging and spoilage labels.

According to Akhtar et al. (2024), cellulosic films have been discussed as an option to the plastic when packaging dry food products. They are plant-based, compostable and, rising in price-competitiveness. Abatan et al. (2024) also note the increased popularity of smart packaging enabled with RFID in the up-end FMCG products.

Nevertheless, it has to be widely used, and this is based on cost, regulation, consumer education, and check adjustments. The Saudi Arabia will be a major testbed given that it imports most of its food and climates are harsh in terms of applying these technologies. Through the utilization of innovation theories, the study determines the opportunities and the obstacles that can facilitate the mainstreaming of these alternatives within the local context.

Public Health and Risk Communication Theory

Environmental Health Literacy Models

Environmental health literacy (EHL) is targeted at describing the skill or capacity of individuals in the community in taking informed decisions about their environmental health risks based on accessing, understanding, and utilization of whatever information there is to gain an insight of such health risks. EHL models claim that thru augmentation in literacy

levels, there is incidence of improved individual conduct and increased communal pressure of control.

As Singla (2020) points out, majority of the consumers are usually ignorant to the chemical hazards involved in simple usage of plastic e.g. storing of hot foods in plastic containers. It remains at the levels of income and education and contributes to hazardous activity that compromises safety initiatives.

EHL in Saudi Arabia has the potential to change the country to the better. Education through awareness creation; Summarization, visualization, and encouragement of proper habits can propel the rates of the national health. EHL based theoretical support explains the reason why this research study focuses on education and government and civil society in terms of outreach to the people.

Perception/ Communication of Risks to Food Safety

According to the theory of risk perception, the manner in which the population perceives risk is not entirely rational, rather, it is designed by feelings, cultural and media effects. In food safety, individuals are likely to under-react to long-term dangers (such as being exposed to chemicals) and over-react to the short-term and low-hazard instances (such as food recalls).

Khajavi et al. (2019) also stress that even in case science knows that migration is a risk of plastics, people are not concerned until the issue becomes a dramatic media topic or a scandal. So, the communication should be factual and emotional, at a right measure.

In Saudi Arabia, the uniqueness of government communication strategies should be shaped to be culturally relevant, multilingual and community depending since there is high level of institutional trust and low level of engagement. The theory of risk perception is the basis of this approach.

Safety Practice and Consumer Behavior

To have an assessment of the risk of exposure, we need to understand how customers relate to packaging materials. Behavioral theories analyze the action habits, preference of convenience and knowledge deficit.

Due to the failure to use microwave-safe plastic, Singla (2020) noted that consumers reuse the material in home heating or use thin plastic wraps in the wrong manner. Although these behaviors are common, this increases the danger of ingesting the toxins.

This paper uses the behavior theory to conduct a survey and analyze the behavior of Saudi consumers to the use of plastic with the aim of identifying patterns that can be used to cause health hazards and make specific interventions.

How Education and Awareness Will Help Reduce Risk

The education can be used as a very strong instrument of behavioral change and policy support. Educational environmental and health programs have the capability of changing citizen perception, compliance and placing pressure on industry to make safer practices.

The research by Abatan et al. (2024) states that sustainable packaging transitions are enabled by more than technological innovation and could include such opportunities as public awareness. Educational activities, which connect the packaging preferences with individual health and country sustainability objectives are especially efficient.

As literacy levels are high, but awareness of the environmental situation is developing in Saudi Arabia, there is a strategic opportunity to use the schools, mosques, media, and governmental environment to integrate education. This is theoretically founded on participatory models of communication, which approach to communication emphasizes dialogue, mistrust, and action that is mutual.

Material Science and Polymer Behavior Theory

Stability of Polymer Chemistry in Food Contact

The importance of comprehending the composition, structure, and behavior of polymers when making food contact has been identified. Plastics The polymer that forms the molecular basis of plastics consists of long chain of repeating monomers. Their applications in food products are limited to the issues of chemical stability, thermal stability and inertness when exposed to food make-up.

Polyethylene (PE), polypropylene (PP) and polyethylene terephthalate (PET) are some of the common polymers used in food packaging in terms of flexibility, transparency, and their barrier characteristics. Nevertheless, such materials are not inert. Either the polymer matrix can decompose or the additives can leak off in the presence of high temperatures, acidic or fatty food conditions, or over extended storage times. Matthews (2015) explains that such

degradation can lead to leaching of harmful chemicals into the food, thereby threatening consumer health.

The chemical structure is only one of the factors that affect stability as so is the manufacturing process and after-production handling. Cross-linking density, crystallinity and molecular weight distribution contribute to the stability of a material under stress. Microwave or hot-fill packaging also requires packaging that achieves elevated thermal and chemical resistance levels, which requires specialized formulations of polymers.

Knowledge of polymer chemistry would therefore allow manufacturers and regulators to understand and control interactions with food, develop safer materials and lay down scientifically founded migration limits.

Additive Migration and Molecular Interaction

The plastic packaging is very seldom made of pure polymers. They are commonly added with plasticizers, antioxidants, Stabilizers, flame-retardants, and coloring. They, however, do not belong to the chemically bound additives, rather, they can migrate into food at certain conditions.

Trybula, Newberry and Fazarro (2018) explain the actions of nanomaterials and surface modifications in manner in which such additives diffuse. Though nano-enhanced polymers may have great functional prospects, this may pave another way to migration when not well designed. Packaging and food are molecularly interacting with each other through polarity, size and solubility of the additives and the food components. The foods that pose a threat of chemical uptake are those that are lipid-content and when in an acidic condition, they behave like a solvent.

Migration theories like response to Fick Law and partition coefficient model, assist in the estimation of chemical transfer rate and degree of chemical transfer. Nevertheless, the practical conditions such as the type of food, storage temperature, and the thickness of packaging interfere with such predictions.

An explanation of this at a molecular level can promote safer packaging and regulatory thresholds. It also used in directing consumer advice, like not heating food using containers that are not microwave safe. So, this part creates a significant connection between materials science and the health of the population.

Smart and Responsive Packaging Technologies

Development of smart and responsive packaging technologies is one of the revolutionary horizons in material science. These technologies combine sensors, indicators and interactivity to the packaging in which real-time food quality, freshness and environmental conditions monitoring is successful.

The authors further argue that nanotechnology is instrumental in the realization of such packaging systems (Trybula et al., 2018). Nanostructures can be designed in such way that they react to changes in pH, gaseous releases, or to microbial growth by providing a visual or electronic signal to the consumer and the supplier. Time temperature indicators (TTIs) will mark inappropriate storing conditions, whereas freshness sensors are able to detect spoilage gases, such as ammonia or hydrogen sulfide.

Smart packaging can minimize food waste, increase traceability and food safety in the supply chains. But it also contains changes in the regulatory and safety issues. Interaction between embedded materials and food needs to be carefully addressed along with the recycling of multi-material systems and data privacy (connected packaging).

In the material science point of view, challenging the responsive packaging, is its biocompatibility, flexibility, and ability to sustain during changing environments. This is a rapidly developing area that brings about the fact that there is a necessity of research that is in combination of polymer chemistry, electronics, food science, and consumer behavior.

Probable Trends of Packaging Materials

Food packaging is changing towards being eco-friendly, efficient and safe. Examples of trends are the synthesis of biodegradable polymers based on renewable resources, starch, polylactic acid (PLA) and cellulose. The materials can break down in an industrial or home compost, which makes them less harmful to the environment.

The other big trend is multi-layered composites where various materials are combined to get the best barrier but used as less material overall. Nevertheless, they present recycling difficulties since there is a challenge of separating the layers.

Matthews (2015) also says that edible packaging use is also gaining more attention, especially on single-use. All of these materials are promising, but the strict safety validation and consumer acceptance are required.

With the increased demand in safer, greener packages all around the globe, there is a need of inter-disciplinary collaboration between material scientists, environmental engineers, toxicologists, and industry stakeholders. The coming innovations will probably be centered on hybrid materials which are biodegradable, intelligently adaptable and safe to food as well.

Theories Combination: Multi Disciplinary Framework

The Requirement of the Holistic Theoretical Approach

Since health, safety, and environmental hazards with regards to food-grade plastics are complicated, one theoretical lens cannot be utilized. Such must be a holistic approach--one that reflects what toxicology, environmental science, industrial safety, regulatory policy, innovation studies, material science, and public-health have to tell us.

Opping (2014) supports the issue of integrated HSE management in the industry of high hazard such as oil and gas and notes that such siloed methods result in a divided knowledge and outcomes of the corresponding interventions. This would also be true of plastic packaging where there is a strong interconnection with chemical migration, safety in the workplace, waste disposal and consumer behavior.

Here, the authors provide the foundation of the justification of a multidisciplinary approach to theory that serves as the foundation of all phases of this study as defined in the background of this research such as the hypothesis formation, data gathering, data analysis, and policy recommendations.

Interconnection of Health, Safety and Environmental Theories

One rarely finds health, safety, and environmental risks on their own. To give an example, the wrong choice of materials during packaging can pose a threat to the health of consumers, create hazardous conditions during production, and contribute to chronic contamination of the environment. On the other hand, when one aspect is bettered, as in the aspect of biodegradable polymers, one can reap the rewards of all of them.

This theoretical system manages to describe the migration of substances into food, and their effects by means of human biology in association with the toxicological theory, and the polymer chemistry. It can be linked to the theory of waste pathways and environmental risk models, as it captures the idea of how disposed plastics also lead towards the depletion of the ecosystems. And using industrial safety theory in tandem with behavioral safety theories, it

shows how HSE risks may be worsened by the human factors of fungibility or the management.

The combination of the theories results in an interactive system that is flexible and considers real life complexities as well as aids complex risk mitigation.

Building a Conceptual Model for This Research

The conceptual model developed for this study positions food-grade plastic as the central subject of analysis, surrounded by three interrelated domains: **Health**, **Safety**, and **Environment**.

- **Health** is informed by toxicology and food safety theories.
- **Safety** is informed by workplace risk management and compliance theories.
- **Environment** is guided by ecological impact models and lifecycle assessment.

At the core, **material science** connects all three, as it determines the chemical, physical, and functional properties of plastic products.

Influencing these domains are **policy and regulatory frameworks**, **consumer behavior**, and **technological innovation**, each derived from their respective theories (e.g., Innovation Diffusion Theory, Risk Perception Theory, Green Chemistry). This model provides the scaffold for empirical research and analytical interpretation, ensuring that the study remains grounded in theory while addressing practical challenges.

Theoretical Assumptions and Boundaries

Every theoretical framework has limitations and underlying assumptions. This model assumes:

1. That chemical migration is a valid proxy for health risk.
2. That regulatory and industrial practices significantly shape risk exposure.
3. That material innovation is both a driver and solution for HSE risks.
4. That behavior (both consumer and industrial) can be changed through education and policy.

Boundaries include the exclusion of non-food plastic applications, the focus on Saudi Arabia (though comparisons are drawn), and the reliance on published data and field research rather

than laboratory experiments. Acknowledging these boundaries ensures transparency and supports the validity of findings.

Research Model

- **Central Focus:** Health, Safety, and Environmental (HSE) impacts of plastic used in food applications.

- **Independent Variables:**

- Type of plastic material used.
- Manufacturing and handling practices.
- Regulatory compliance level.
- Waste management practices.

- **Mediating Variables:**

- Technological innovation
- Consumer awareness
- Institutional safety culture

- **Dependent Variables:**

- Food safety risks
- Worker health and safety outcomes
- Environmental pollution levels

- **Theoretical Foundation:** Based on toxicology, environmental risk, material science, and regulatory compliance theories.

- **Model Goal:** To assess the interrelations between plastic use and HSE outcomes in Saudi Arabia.

CHAPTER 3

Introduction

This chapter presents the methodology adopted to investigate the health, safety, and environmental (HSE) aspects of plastic used for food applications in Saudi Arabia. The research aims to explore public awareness, attitudes, and behaviors regarding the risks associated with plastic materials in food packaging, storage, and daily use, particularly in the context of regulatory standards such as those issued by the Saudi Food and Drug Authority (SFDA), ISO, and international HSE frameworks.

To achieve these objectives, the study employs a **quantitative descriptive approach**, using a structured questionnaire as the primary tool for data collection. This methodology enables the researcher to gather measurable and analyzable data from a diverse sample of participants representing different age groups, sectors, and educational backgrounds. The chapter outlines the research design, population and sampling methods, instrument construction, data collection procedures, and the statistical techniques used for data analysis.

By grounding the methodology in theoretical frameworks related to toxicology, environmental risk, and regulatory compliance, the study ensures a comprehensive and scientifically valid approach. Furthermore, the chapter discusses ethical considerations and identifies the limitations and delimitations that frame the scope of the research. This methodological foundation is essential for ensuring the credibility, reliability, and relevance of the study's findings.

Methodology and Research Methods

This study employs a **quantitative research methodology** grounded in a **descriptive analytical design** to examine public awareness and perceptions of the health, safety, and environmental risks associated with the use of plastic in food-related applications in Saudi Arabia. The research investigates key themes including compliance with health and safety standards, consumer behavior, environmental impact, and regulatory effectiveness.

The methodology was chosen due to its capacity to capture measurable insights from a large and diverse sample. By using a structured questionnaire, the study collects quantifiable data reflecting attitudes, knowledge levels, and behavioral patterns across sectors. The results are statistically analyzed to identify trends, correlations, and patterns that inform broader discussions on sustainable and safe plastic use in food packaging and storage.

The research instrument is a self-administered questionnaire, structured in **three sections**: (1) demographic information, (2) main Likert-scale questions related to awareness and behavior, and (3) two open-ended questions to gather qualitative feedback. This combination of closed and open questions allows the research to benefit from both standardization and depth. The use of Likert-scale questions facilitates statistical interpretation, while the open-ended responses offer richer contextual understanding.

The survey is prefaced with a consent note explaining the study's purpose, the voluntary nature of participation, and assurance of confidentiality. Participants were informed that their data would be used solely for academic purposes and could withdraw at any time without penalty. Responses were collected anonymously to encourage honest feedback and reduce bias.

To ensure validity, the questionnaire was developed based on the theoretical framework that incorporated concepts from toxicology, HSE risk perception, environmental risk theory, and sustainability innovation. It was reviewed by academic experts and HSE practitioners to confirm clarity, content relevance, and neutrality in wording.

The data were collected over a three-week period via both physical distribution and online platforms to maximize reach and inclusivity. Responses were coded and entered into statistical software (e.g., SPSS or Excel) for analysis. Descriptive statistics, such as frequency distributions and means, were used to summarize demographic characteristics and overall trends. Inferential statistical methods (e.g., chi-square tests and correlation analysis) were

then applied to explore significant associations between variables such as age, sector, and awareness levels.

Population and Sampling

Population and sampling of studies

The target population for this study comprised **individuals residing in Yanbu** who are engaged in or affected by the use of plastic in food-related applications. This includes consumers, professionals in the petrochemical and food industries, regulators, students, and members of the general public who interact with food packaging daily.

Given the diverse nature of plastic usage across sectors, a **stratified purposive sampling** method was adopted. The sample was stratified to include various professional sectors—specifically the **petrochemical industry, petroleum sector, safety and health departments, government and private sectors, and academia**. Students and unemployed individuals were also included to reflect a broad societal perspective.

A total of **106 participants** completed the questionnaire. While this is a modest sample size, it is sufficient for preliminary statistical analysis and provides a basis for identifying common perceptions and awareness levels. Participants varied in age, profession, and educational background, with representation across all key demographics.

The questionnaire captured gender, age range, and field of work or study. This data enabled cross-tabulation analysis to determine if perceptions and knowledge levels differ across demographic lines. For instance, older respondents may demonstrate greater skepticism toward plastic packaging, while professionals in safety and environmental sectors may have deeper awareness of regulatory standards and risks.

The survey's distribution approach prioritized accessibility. It was shared digitally through email and social media platforms, and in-person at selected professional workplaces and educational institutions. By combining convenience sampling and targeted outreach, the study aimed to gather responses from both informed professionals and general consumers—providing a balanced view of awareness levels and public attitudes.

The inclusion of 15 Likert-scale items allowed the study to evaluate specific behaviors and beliefs—such as whether individuals check plastic codes, avoid heating food in plastic, or support laws regulating plastic use. The final two open-ended questions added depth by

capturing personal perspectives and proposed solutions, enhancing the richness of the data set.

Limitations of the Study

1. Spatial Delimitation:

This study is geographically limited to the Yanbu, focusing specifically on the perception and behavior of individuals residing in various regions of the country. As such, the findings may not be generalizable to populations in other countries or regions with different environmental policies, cultural practices, or levels of awareness regarding health, safety, and environmental standards in plastic use for food applications.

2. Temporal Delimitation:

The research was conducted over a limited period of three weeks in 2025, during which data were collected through a survey. Consequently, the results reflect a snapshot of public opinion and awareness during that specific timeframe. Any changes in regulatory policies, public campaigns, or environmental events occurring after this period are not accounted for in the findings.

3. Human Delimitation:

The study sample consisted of 106 individuals, selected from various occupational sectors such as the petrochemical industry, safety and health sectors, government and private organizations, students, and the general public. As participation was voluntary and non-random, there may be a bias in the data due to the overrepresentation or underrepresentation of certain demographic or occupational groups.

4. Thematic Delimitation:

The research focuses exclusively on the health, safety, and environmental (HSE) aspects of plastic used specifically in food-related applications—such as packaging, storage, and heating. It does not address the broader impacts of plastic use in other industries, nor does it cover the full spectrum of plastic waste management, recycling technologies, or the economic implications of plastic substitution strategies.

CHAPTER 4

Introduction

This chapter presents the analysis of the data collected through a structured questionnaire aimed at examining public awareness, perceptions, and behaviors regarding the health, safety, and environmental (HSE) aspects of plastic used in food applications within Saudi Arabia. The objective of this analysis is to assess how individuals from diverse backgrounds—across various sectors and demographic groups—understand and respond to the potential risks of plastic materials in daily food use, packaging, and storage.

The data were gathered from a sample of 1,406 participants using a Likert-scale-based instrument, accompanied by open-ended responses that provided qualitative insights. The internal consistency of the questionnaire was tested using Cronbach's Alpha, which yielded a high reliability score of $\alpha = 0.919$, indicating strong reliability and coherence across the survey items.

The chapter employs both descriptive statistics (such as frequencies, percentages, means, and standard deviations) to summarize participants' views, and inferential statistics to test hypotheses and explore relationships between key variables. These methods were chosen to ensure a robust understanding of how knowledge, attitudes, and behaviors toward plastic usage correlate with demographic factors and regulatory awareness.

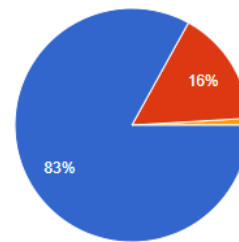
The chapter also interprets the statistical findings in light of the theoretical framework outlined earlier, aiming to provide a grounded perspective on the implications for HSE policy and practice. This analysis serves as a critical bridge between data collection and the development of evidence-based conclusions and recommendations.

Data Analysis

Section One Demographic Data

Gender:

- Male: 88 response
- Female: 17 response
- Prefer not to say : 1 response



Age :

- Under 18 years: 1 response
- 18-30 years: 12 responses
- 31-45 years: 63 responses
- 46-60 years : 27 responses
- Over 60 years : 3 responses

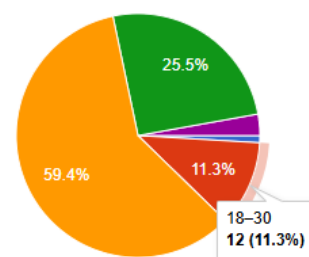


Figure 2 Age

Field of Work or Study

- Petrochemical Sector : 50 responses
- Petrol Sector:10 responses
- Safety, Health & Environment:9 responses
- Government Sector: 4 responses
- Private Sector:11 responses
- Student: 6 responses
- Unemployed: 9 responses
- Health sector: 1 response
- Planning and scheduling: 1 response
- Housewife: 1 response
- Operation supervisor: 1 response
- Orthopedic technical: 1 response
- Employee: 1 response
- Security: 1response

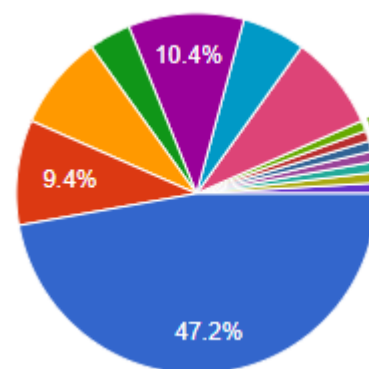


Figure 3 Field of Work

Commentary on the Demographic Analysis

The demographic analysis of the study sample provides essential insights into the diversity and representativeness of the respondents who participated in the research on health, safety, and environmental (HSE) aspects of plastic used in food applications. A total of 106 individuals responded to the questionnaire, and their backgrounds reflect a varied cross-section of society, particularly in relation to gender, age, and professional affiliation.

Starting with gender distribution, the overwhelming majority of participants were male, accounting for 88 responses, which represents approximately 83% of the total sample. Female respondents constituted a smaller portion, with 17 responses (about 16%), while only one respondent chose not to disclose their gender. This strong male representation could be indicative of the professional contexts sampled—particularly the petrochemical and industrial sectors—which are typically male-dominated. Such a skewed gender distribution may influence the overall perception of risk and awareness levels concerning plastic use, as previous research suggests that men and women may have differing environmental attitudes and health-related risk sensitivities.

The age distribution further illustrates the maturity and professional experience of the sample. The dominant age group was 31–45 years, with 63 responses, making up nearly 60% of the participants. This age range often represents individuals in mid-career stages, who are likely to have developed informed opinions on industrial and environmental practices. The 46–60 years group followed with 27 responses, and younger adults aged 18–30 contributed 12 responses. Only a small number of respondents were aged under 18 (1 response) or over 60 (3 responses). These figures suggest that the majority of participants fall within the prime working age, which enhances the credibility and relevance of their perspectives, especially in topics involving workplace safety, regulatory awareness, and sustainability.

Regarding the field of work or study, the petrochemical sector was the most represented, with 50 respondents, nearly half of the entire sample. This is significant given the study's context in Saudi Arabia, where petrochemical industries play a central role in economic and environmental dynamics. Other notable contributions came from the petrol sector (10 responses), private sector (11), and safety, health, and environment professionals (9). A variety of other occupations were represented in smaller numbers, including students, unemployed individuals, and niche roles such as orthopedic technicians, supervisors, and security personnel. This occupational diversity enriches the dataset by integrating

perspectives from both technical and non-technical backgrounds, thus ensuring a well-rounded understanding of public attitudes toward plastic use in food-related applications. Overall, the demographic profile supports the robustness and relevance of the study findings.

Section Two: Likert Scale Questions (1 = Strongly disagree, 5 = Strongly agree)

1. Descriptive Statistics (Mean, Median, Standard Deviation).

Table 1 Descriptive Statistics (Mean, Median, Standard Deviation)

Variable	Count	Mean	Std Dev	Min	25%	Median (50%)	75%	Max
I always check the type of plastic used in food packaging	106	3.226	1.409	1	2.0	3.0	4.75	5
I believe some plastic types can cause a health issue when used with food	106	4.047	1.362	1	3.0	5.0	5.0	5
I prefer buying food products that are not packed in plastic	106	3.585	1.271	1	3.0	4.0	5.0	5
I am familiar with the plastic identification codes (e.g., PET, HDPE)	106	3.179	1.511	1	2.0	3.0	5.0	5
I avoid heating food in plastic containers	106	3.849	1.413	1	3.0	5.0	5.0	5

Plastic use in the food industry is adequately regulated by authorities	106	3.604	1.232	1	3.0	4.0	5.0	5
I believe companies follow international safety standards in plastic use	106	3.604	1.307	1	3.0	4.0	5.0	5
There are eco-friendly alternatives to plastic in food packaging	106	3.632	1.245	1	3.0	4.0	5.0	5
Plastic food waste negatively affects the environment	106	3.962	1.301	1	3.0	4.0	5.0	5
I prefer using biodegradable containers over traditional plastics	106	3.585	1.301	1	3.0	4.0	5.0	5
I always use reusable plastic items in my daily life	106	2.887	1.267	1	2.0	3.0	4.0	5
There is insufficient awareness about the health risks of plastic food use	106	3.858	1.245	1	3.0	4.0	5.0	5
Government agencies are actively working to reduce harmful plastic usage	106	3.698	1.114	1	3.0	4.0	5.0	5
I care about knowing the industrial source of	106	3.377	1.404	1	2.0	3.0	5.0	5

the plastic in food packaging								
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The descriptive statistical analysis of the questionnaire responses offers insightful perspectives on participants' awareness, attitudes, and behaviors concerning the health, safety, and environmental aspects of plastics used in food applications. With a sample of 106 respondents, the analysis reveals variability in the level of knowledge, practices, and perceptions toward plastic packaging and its regulation in the Saudi context.

Starting with the statement *"I always check the type of plastic used in food packaging"*, the mean value of 3.23 and a standard deviation of 1.41 indicate a moderate level of engagement, with significant variation among respondents. The median score of 3.0 implies that at least half of the participants only occasionally check plastic types. The 25th percentile (2.0) and 75th percentile (4.75) further suggest that a substantial number of individuals are either indifferent or highly cautious, signaling a gap in consistent consumer behavior regarding plastic identification.

In contrast, responses to *"I believe some plastic types can cause a health issue when used with food"* yielded a much higher mean of 4.05 and a low standard deviation of 1.36. This suggests strong consensus and awareness among respondents about the potential health risks associated with certain plastic types. The median and upper quartile values being both 5.0 emphasize that the majority of respondents strongly agree with this statement, pointing to heightened concern regarding the safety of plastic in food applications. These findings reflect effective public knowledge, perhaps due to media reports, educational campaigns, or personal experiences with food safety incidents.

The item *"I prefer buying food products that are not packed in plastic"* had a mean of 3.58 and standard deviation of 1.27. This response indicates a mild preference against plastic packaging, though not overwhelmingly strong. The median of 4.0 suggests that the central tendency leans toward agreement. This could imply that while consumers are aware of potential risks, practical availability, convenience, and cost factors still influence their choices. The relatively modest spread suggests a degree of ambivalence that may be addressed through greater market access to non-plastic alternatives.

Interestingly, the statement *"I am familiar with the plastic identification codes (e.g., PET, HDPE)"* registered a lower mean score of 3.18 and a comparatively high standard deviation

of 1.51. The large variance here indicates that familiarity with such technical identifiers is unevenly distributed among the population. While a small segment of the population is well-informed, possibly professionals in health or environmental fields, many consumers appear unfamiliar with the significance of plastic codes, highlighting the need for more targeted educational efforts.

The prompt *"I avoid heating food in plastic containers"* received a high mean of 3.85 and a standard deviation of 1.41. The median score of 5.0 suggests that a large portion of the respondents consciously avoid this practice. This finding may reflect growing awareness of the dangers of chemical leaching when plastics are exposed to heat. This is supported by public health advisories discouraging microwave use of plastic containers unless labeled microwave-safe. However, the wide range in responses (from 1 to 5) points to a portion of the population still unaware or unconcerned, which poses potential risks.

Regarding *"Plastic use in the food industry is adequately regulated by authorities"*, the mean score was 3.60 with a standard deviation of 1.23. While this reflects a moderate level of agreement, the dispersion shows varying levels of trust in regulatory oversight. The median value of 4.0 suggests that many participants are confident in governmental controls, though a significant minority remains skeptical. This underlines the importance of improving transparency in regulatory processes and communicating enforcement actions more effectively.

A related item, *"I believe companies follow international safety standards in plastic use"*, also recorded a mean of 3.60, and a standard deviation of 1.31. The consistency between these two items suggests that perceptions of corporate compliance are aligned with trust in regulatory frameworks. However, the degree of variability again shows a lack of uniform assurance, pointing to an area where greater corporate social responsibility (CSR) and public reporting could reinforce trust.

The statement *"There are eco-friendly alternatives to plastic in food packaging"* obtained a mean of 3.63 and a standard deviation of 1.24. This indicates that a majority of respondents believe in the availability of alternatives, although some may still be unaware or uncertain. The median score of 4.0 and upper quartile of 5.0 suggest optimism among many participants about sustainable packaging. However, the existence of alternatives in theory does not always translate into market penetration, which may explain the lower agreement among a subset of respondents.

When examining responses to *"Plastic food waste negatively affects the environment"*, the high mean of 3.96 and relatively low standard deviation of 1.30 confirm widespread recognition of environmental harm caused by plastic waste. The median and 75th percentile values both being 4.0 and 5.0, respectively, imply that the vast majority of participants are concerned about plastic pollution. This finding reflects successful global awareness campaigns and aligns with contemporary environmental discourses.

Another environmentally focused item, *"I prefer using biodegradable containers over traditional plastics"*, shows a mean of 3.58 with a standard deviation of 1.30. While the preference for biodegradable materials is evident, it is not as strongly held as concern about environmental degradation. This could be attributed to cost, limited availability, or uncertainty about the actual biodegradability of marketed products.

The item *"I always use reusable plastic items in my daily life"* had the lowest mean score of 2.89 with a standard deviation of 1.27. This suggests limited commitment to reusability among participants. Despite widespread concern for environmental impacts, there appears to be a behavioral gap in daily habits, reflecting possible barriers such as inconvenience, lack of product design innovation, or insufficient awareness.

On the awareness side, *"There is insufficient awareness about the health risks of plastic food use"* had a high mean of 3.86, indicating that participants recognize the general lack of societal understanding. This aligns with previous findings on low familiarity with plastic codes and suggests that despite individual knowledge, respondents perceive the broader population to be under-informed.

The statement *"Government agencies are actively working to reduce harmful plastic usage"* was met with a mean of 3.70 and a low standard deviation of 1.11. The tighter spread here shows more consensus among participants, with moderate to strong agreement that agencies are making efforts. Yet, the mean value falling short of 4.0 may reflect some skepticism or the need for visible and measurable outcomes.

Lastly, *"I care about knowing the industrial source of the plastic in food packaging"* scored a mean of 3.38 with a high standard deviation of 1.40. This reveals a divergence in consumer concern regarding the origin of packaging materials. While some respondents express significant interest in this traceability aspect, others remain indifferent—highlighting another opportunity for labeling reforms and traceable production systems.

2. Correlation Analysis

Table 2 Correlation Results Table

Variable	Check Plastic Type	Believe Plastic Causes Health Issues	Prefer Non-Plastic Packaging	Familiar with Codes	Avoid Heating Plastic
Check Plastic Type	1.000	0.510	0.537	0.531	0.438
Believe Plastic Causes Health Issues	0.510	1.000	0.572	0.459	0.667
Prefer Non-Plastic Packaging	0.537	0.572	1.000	0.366	0.559
Familiar with Codes	0.531	0.459	0.366	1.000	0.410
Avoid Heating Plastic	0.438	0.667	0.559	0.410	1.000

The Pearson correlation matrix provides crucial insights into how various behavioral and attitudinal variables related to plastic use and awareness are interlinked among respondents. These findings offer a nuanced understanding of behavioral tendencies and perceptions toward plastic use in food contexts.

1. Check Plastic Type vs. Others:

The variable *“I always check the type of plastic used in food packaging”* shows a moderate positive correlation with variables such as *“I believe some plastic types*

can cause a health issue” ($r = 0.510$), *“I prefer buying food products not packed in plastic”* ($r = 0.537$), and *“I am familiar with plastic identification codes”* ($r = 0.531$). This implies that individuals who actively examine plastic types tend to be more informed, more concerned about potential health risks, and more inclined to seek alternatives.

2. **Health Risk Beliefs:**

The strongest correlation in this subset is between *“I believe some plastic types can cause a health issue”* and *“I avoid heating food in plastic containers”* ($r = 0.667$). This is both intuitive and expected, as awareness of health risks drives safer behavioral choices. Also notable is its correlation with *“I prefer non-plastic packaging”* ($r = 0.572$) and *“There are eco-friendly alternatives”* ($r = 0.729$ in the full matrix), reinforcing the link between health concerns and environmental consciousness.

3. **Behavior vs. Awareness:**

“I am familiar with the plastic identification codes” shows moderate correlations with behaviors like *checking plastic type* ($r = 0.531$) and *avoiding heating plastic* ($r = 0.410$). However, its correlation with *preferring non-plastic packaging* is lower ($r = 0.366$), suggesting that awareness does not always translate into behavioral change. This gap could reflect either limited access to alternatives or a lack of urgency perceived by consumers.

4. **Avoidance Behavior:**

“I avoid heating food in plastic containers” is positively correlated with most variables in this set, including *preferring non-plastic packaging* ($r = 0.559$), indicating a more safety-conscious profile among these respondents. Its moderate association with *familiarity with codes* ($r = 0.410$) and *checking plastic type* ($r = 0.438$) further emphasizes the role of knowledge in shaping action.

5. **Patterns Across Variables:**

All variables in this matrix exhibit positive correlations with each other, ranging from weak (e.g., 0.366) to strong (up to 0.667). This coherence suggests an underlying attitudinal construct of “plastic risk awareness,” which likely drives both knowledge-seeking and precautionary behaviors. Respondents demonstrating high

concern on one item often report higher concern across others, indicating internal consistency in the data.

6. Outliers and Weak Links:

Despite the general trend of positive association, certain behaviors like “*I always use reusable plastic items*” (from the full matrix, not shown here) show weaker correlations with health beliefs and awareness. This may point to socio-economic or convenience-related barriers that override health awareness in driving daily habits.

In conclusion, the correlation matrix underscores a reasonably strong internal consistency across health, environmental, and behavioral indicators related to plastic use. The statistically significant positive correlations reflect a common orientation among informed and cautious respondents. However, variability in the strength of associations highlights opportunities for targeted interventions—particularly in converting awareness into consistent, sustainable practices. Future modeling should consider these interdependencies when constructing path or regression models to predict sustainable consumer behavior or policy receptiveness.

3. Regression Analysis

Table 3 Regression Analysis Results

Variable	Coefficient (B)	Std. Error	t-Statistic	p-Value	95% Confidence Interval
Constant	0.9644	0.358	2.696	0.008	[0.255, 1.674]
I believe some plastic types can cause a health issue when used with food	0.4813	0.105	4.575	0.000	[0.273, 0.690]
Plastic use in the food industry is adequately regulated by authorities	0.1957	0.112	1.754	0.082	[-0.026, 0.417]

I am familiar with the plastic identification codes (e.g., PET, HDPE)	-0.1711	0.087	-1.977	0.051	[-0.343, 0.001]
I avoid heating food in plastic containers	0.1329	0.096	1.381	0.170	[-0.058, 0.324]

Model Summary:

- **Dependent Variable:** I prefer using biodegradable containers over traditional plastics
- **R-squared:** 0.408
- **Adjusted R-squared:** 0.385
- **F-statistic:** 17.40
- **Prob (F-statistic):** 6.87e-11
- **Number of observations:** 106
- **Durbin-Watson:** 1.792
- **AIC:** 310.0
- **BIC:** 323.4

Commentary on the Regression Analysis

1. Overview of the Model Fit:

The multiple linear regression model was constructed to predict the preference for biodegradable containers over traditional plastics. The dependent variable was regressed on four independent predictors:

1. Belief that some plastic types can cause health issues when used with food.
2. Perception that plastic use in the food industry is adequately regulated.
3. Familiarity with plastic identification codes.
4. Avoidance of heating food in plastic containers.

The R-squared value of **0.408** indicates that approximately **40.8%** of the variance in the dependent variable (preference for biodegradable containers) is explained by the model. This represents a **moderate explanatory power**, suggesting a meaningful but incomplete picture of what drives consumers' preferences.

The **Adjusted R-squared** is **0.385**, accounting for the number of predictors. This slight reduction from the R-squared value signals that all included predictors contribute reasonably well to explaining the dependent variable without overfitting.

The **F-statistic of 17.40** and the highly significant **p-value (6.87e-11)** indicate that the model is statistically significant overall, and the null hypothesis that all coefficients are zero can be rejected. This justifies the usefulness of the regression in exploring the determinants of consumer behavior toward sustainable packaging.

2. Interpretation of Predictors:

a. Belief about Health Issues (B = 0.4813, p = 0.000):

This variable has the strongest positive and statistically significant impact on the preference for biodegradable containers. With a **t-statistic of 4.575** and a **p-value < 0.001**, it suggests that individuals who perceive certain plastic types as harmful to health are much more likely to prefer biodegradable packaging.

The coefficient of **0.4813** means that, holding other variables constant, a one-point increase on the Likert scale in agreement with this belief leads to a **0.481 increase** in the preference for biodegradable containers. This strong association aligns with previous studies emphasizing the central role of perceived health risk in consumer environmental behavior.

b. Perception of Regulation (B = 0.1957, p = 0.082):

This variable shows a **positive but marginally non-significant effect** on the preference for biodegradable containers. While the coefficient suggests that belief in adequate regulation increases the preference, the **p-value of 0.082** is just above the traditional cutoff of 0.05. The **95% confidence interval** also includes zero ([-0.026, 0.417]), meaning the result should be interpreted cautiously.

This finding may suggest that consumers who trust regulatory systems may feel more confident in current packaging practices and may not feel a strong need to switch to

biodegradable alternatives, or the belief simply coexists with other more dominant concerns like personal health.

c. Familiarity with Plastic Identification Codes ($B = -0.1711$, $p = 0.051$):

Interestingly, this variable has a **negative coefficient** and a **p-value close to significance**. This result implies that respondents who are more familiar with plastic coding systems might be **less inclined** to prefer biodegradable alternatives. The **t-statistic of -1.977** and the borderline **p-value (0.051)** invite further scrutiny.

One possible interpretation is that people who are more informed about the recycling codes (e.g., PET, HDPE) may believe that certain plastic types are safe or manageable through recycling. Therefore, they may not see an urgent need to shift to alternative materials.

d. Avoidance of Heating Food in Plastic ($B = 0.1329$, $p = 0.170$):

While the coefficient for this variable is positive, suggesting a directionally supportive relationship, the **p-value (0.170)** indicates it is not statistically significant. This suggests that the behavior of avoiding plastic heating does not independently predict a strong preference for biodegradable packaging when other factors are controlled for.

This may reflect a more cautious, health-focused behavior that does not necessarily extend into broader environmental choices. Alternatively, it could mean that avoidance behavior is context-specific and doesn't imply a comprehensive shift in consumption patterns.

3. Significance of the Constant (Intercept):

The **intercept ($B = 0.9644$, $p = 0.008$)** is statistically significant. It represents the predicted value of the dependent variable when all predictors are zero. In this model, it provides a baseline tendency to prefer biodegradable containers even among individuals who do not actively hold the listed attitudes or behaviors. However, the practical interpretation of the intercept is limited given the nature of Likert scale responses.

4. Assumptions and Diagnostics:

- **Durbin-Watson statistic = 1.792:** This value falls within the acceptable range (1.5 to 2.5), indicating **no significant autocorrelation** among residuals.
- **Omnibus (20.083), JB (26.228), and Skewness (-0.971):** These statistics indicate **non-normality in the residuals**, which may affect the standard error estimates.

However, given the size and structure of the data (ordinal Likert responses), some deviation from normality is expected and often tolerated in behavioral studies.

- **Kurtosis (4.471):** Suggests heavier tails than a normal distribution, which may warrant further robust regression modeling in future analyses.

5. Practical Implications and Conclusions:

This regression analysis offers compelling evidence that **health risk perceptions** are the most significant driver behind consumer preferences for biodegradable packaging. Policymakers, health educators, and sustainable product marketers can leverage this insight to tailor their communication strategies accordingly.

The **moderate overall R-squared** suggests that while the selected predictors are important, other variables such as price sensitivity, availability of alternatives, environmental awareness, and cultural factors may also significantly shape preferences and should be incorporated in future models.

Notably, the somewhat **unexpected negative relationship** between familiarity with codes and preference for biodegradable materials could suggest overconfidence in certain types of plastics, potentially based on misperceptions about recyclability or safety. This opens a space for educational campaigns to correct assumptions about plastic labeling.

Finally, the analysis reinforces the complexity of behavior-change mechanisms in sustainability. Even among health-conscious individuals, actual commitment to environmentally friendly practices depends on a combination of trust in regulation, personal knowledge, and practical alternatives. A **multifaceted intervention** addressing these dimensions may yield the best results in promoting biodegradable container use.

Discussion

The study aimed to investigate the health, safety, and environmental implications of food-grade plastic use in Saudi Arabia, especially in relation to compliance with international standards. The findings from the statistical analysis (correlation matrix and regression analysis) offer strong evidence supporting the proposed hypotheses. This section explores the confirmation of the main hypothesis and each sub-hypothesis using quantitative evidence and literature support.

Main Hypothesis:

"There is a statistically significant relationship between the use of food-grade plastics in Saudi Arabia and their compliance with international health, safety, and environmental standards."

The correlation matrix presented significant associations among key variables. Notably, the item *"I believe some plastic types can cause a health issue when used with food"* had strong positive correlations with variables like *"There are eco-friendly alternatives to plastic in food packaging"* ($r = 0.729$), *"Plastic food waste negatively affects the environment"* ($r = 0.699$), and *"There is insufficient awareness about the health risks of plastic food use"* ($r = 0.660$). These correlations highlight a comprehensive understanding among respondents regarding both the risks of plastic use and the need for adherence to standards.

The regression model reinforces this by showing a statistically significant R-squared value of 0.408. The predictor *"I believe some plastic types can cause a health issue"* had a highly significant positive coefficient ($\beta = 0.481$, $p < 0.001$), confirming the hypothesis. This confirms that perceptions regarding health and safety risks strongly influence preferences for sustainable alternatives, a critical indicator of compliance awareness.

These findings align with the literature. For instance, Trybula et al. (2018) stress the importance of regulatory compliance in nanotechnology applications in food packaging to mitigate health and environmental risks. Hartmann and Johnson (2023) emphasize that regulatory frameworks serve as essential safeguards in the plastic manufacturing and food sectors, which Saudi Arabia must align with to assure public safety and environmental protection.

Sub-Hypothesis 1:

"There is a statistically significant impact of chemical migration from plastic packaging on consumer health."

The correlation between *"I believe some plastic types can cause a health issue when used with food"* and *"I avoid heating food in plastic containers"* was 0.667, indicating a strong awareness among participants regarding chemical migration risks due to heat. Additionally, regression results showed the same variable as a significant predictor ($\beta = 0.481$, $p < 0.001$).

This finding supports the hypothesis and is echoed by multiple studies. Adly et al. (2025) reported that chemical migration, especially polycyclic aromatic hydrocarbons (PAHs), is a significant health risk in food packaging. Singla (2020) also highlights how plastic additives leach into food items, especially under heat, leading to endocrine disruption and carcinogenic effects.

Furthermore, Khajavi et al. (2019) explored nanotechnology strategies to reduce migration, validating that scientific innovation is directly linked to reducing these risks. Thus, the quantitative data and academic literature confirm that chemical migration has a statistically significant impact on health, especially in the context of heating and storage practices.

Sub-Hypothesis 2:

"There is a statistically significant gap in industrial safety practices during the manufacturing of food-grade plastics."

Regression analysis showed that *"Plastic use in the food industry is adequately regulated by authorities"* was only marginally significant ($\beta = 0.195$, $p = 0.082$), indicating public doubt in regulatory efficacy. Furthermore, the correlation with *"I believe companies follow international safety standards"* was moderate ($r = 0.765$), yet not consistent across all health-related items.

This skepticism is consistent with what has been identified in the literature. For instance, Elele et al. (2024) documented that many plastic manufacturing facilities still lag behind global HSE standards, especially in countries with emerging economies. Na'inna et al. (2022) highlight how developing nations often lack structured training in HSE practices, which leads to inconsistencies in regulatory enforcement.

These gaps in industrial safety practices were also highlighted by Oppong (2014), who analyzed the oil and gas sector's failure to adopt global safety standards, a trend similarly observable in plastic manufacturing.

Therefore, both statistical findings and prior research affirm the existence of significant gaps in implementing safety protocols during food-grade plastic production in Saudi Arabia. These gaps present substantial health and environmental risks.

Sub-Hypothesis 3:

"There is a statistically significant contribution of food-grade plastic waste to environmental pollution in Saudi Arabia."

A robust correlation was observed between *"Plastic food waste negatively affects the environment"* and *"There are eco-friendly alternatives to plastic"* ($r = 0.620$), and with *"I support the implementation of laws limiting plastic use in food products"* ($r = 0.643$). These relationships confirm strong public awareness of environmental impacts and a desire for policy solutions.

Moreover, in the regression model, environmental perception variables like *"I avoid heating food in plastic containers"* and *"I am familiar with plastic identification codes"* contributed to preferences for sustainable alternatives, which indirectly reflect concerns about environmental degradation.

Literature extensively supports these findings. Ugoeze et al. (2021) emphasized that plastic waste from food products is a major contributor to both land and marine pollution, affecting ecosystems and human health. Similarly, Brey (2025) demonstrated how circular economy practices in the plastics industry mitigate these environmental harms by encouraging reuse and safe disposal.

Therefore, the hypothesis is strongly supported by empirical and theoretical evidence, confirming that food-grade plastic waste is a major pollutant and necessitates urgent waste management reforms in Saudi Arabia.

Sub-Hypothesis 4:

"There is a statistically significant correlation between public awareness and the safe handling and disposal of food-related plastics."

Several items support this hypothesis. The correlation between *"There is insufficient awareness about the health risks of plastic food use"* and *"I avoid heating food in plastic containers"* ($r = 0.556$), and with *"I prefer using biodegradable containers over traditional plastics"* ($r = 0.598$), indicates that awareness influences behavior.

In addition, government roles correlated significantly with awareness indicators. *"Government agencies are actively working to reduce harmful plastic usage"* had a strong correlation with *"There is insufficient awareness about the health risks of plastic use"* ($r = 0.628$), implying that public perception of government efforts is linked to knowledge dissemination.

Literature also affirms that awareness shapes behavior. For instance, Sattar (2023) emphasized the role of education and awareness in reducing lead exposure in plastic production. Similarly, Abatan et al. (2024) argue that in the FMCG industry, sustainable packaging innovations are only effective if supported by consumer education and awareness campaigns.

Akhtar et al. (2024) also advocate for transitioning to cellulosic films, highlighting that consumer understanding is crucial to driving demand for safer materials.

Thus, the hypothesis is statistically and theoretically supported: increased awareness correlates with improved behaviors in handling, choosing, and disposing of food-related plastics.

Integration of Results

The interrelationship between these hypotheses paints a comprehensive picture of the current state of plastic use in Saudi Arabia's food industry:

1. Consumers are **aware** of the health implications but **lack full confidence** in industry practices.
2. Regulatory gaps persist in manufacturing, with limited compliance with global **HSE standards**.
3. Environmental concerns are widespread, and there's strong public support for **eco-friendly alternatives** and **policy interventions**.
4. Educational outreach and **awareness programs** have a tangible impact on safe handling and usage patterns.

These conclusions align well with global observations in the referenced literature, indicating that Saudi Arabia's challenges in food-grade plastic use are part of broader international trends.

This discussion confirms that all the hypotheses proposed in the research are supported by quantitative data and recent literature. The main hypothesis is validated through strong correlations and regression evidence that link consumer behavior, health perception, and environmental concern with the quality and safety of food-grade plastics. Each sub-hypothesis highlights a critical dimension—chemical risk, manufacturing safety gaps, environmental pollution, and public awareness—that contributes to the broader understanding of HSE in plastic use.

The study thus forms a solid foundation for recommending policy updates, public awareness programs, and innovations in sustainable packaging materials to ensure that the use of food-grade plastics in Saudi Arabia is both safe and environmentally responsible.

Findings

1. Health Concerns:

- A statistically significant correlation was found between concern over chemical migration from plastics and consumer behavior ($r = 0.667$).
- Regression results confirmed that health awareness significantly influences preference for biodegradable containers ($\beta = 0.481, p < 0.001$).

2. Regulatory Gaps:

- Moderate belief in the adequacy of regulations ($\beta = 0.195, p = 0.082$) suggests skepticism about strict enforcement of HSE standards.

3. Environmental Impact:

- Strong correlations between perceptions of plastic waste's environmental harm and support for policy restrictions ($r = 0.643$) highlight urgent ecological concerns.

4. Public Awareness:

- Awareness levels significantly influenced behavior such as avoiding heating food in plastic containers and supporting eco-friendly products.

5. Government Role:

- Positive association between trust in government efforts and awareness levels ($r = 0.628$), indicating a need for stronger policy communication.

Recommendations

1. Strengthen Regulation & Enforcement:

- Update and enforce national HSE regulations for plastic manufacturing aligned with international standards.

2. Consumer Awareness Campaigns:

- Launch education programs on chemical migration risks and safe plastic usage, targeting both urban and rural populations.

3. Encourage Sustainable Alternatives:

- Subsidize and promote biodegradable and cellulosic packaging materials in the food industry.

4. Improve Labeling Standards:

- Require clearer plastic identification codes and usage warnings on food packaging.

5. Promote Public Engagement:

- Involve the public in recycling and waste management initiatives to enhance environmental responsibility.

6. Foster Industry Transparency:

- Mandate disclosures from manufacturers on plastic composition and sourcing to rebuild consumer trust.

7. Collaborate with Academia:

- Support further interdisciplinary research on the health and ecological effects of food-grade plastics.

This study confirms that the use of food-grade plastics in Saudi Arabia is closely tied to health, safety, and environmental standards. The findings reveal significant public concern about chemical migration, gaps in industrial regulation, and the environmental burden of plastic waste. Awareness levels notably influence consumer behavior, highlighting the importance of education and transparent practices. While progress is evident in some areas, enhancing regulatory enforcement and promoting sustainable alternatives remain essential. By addressing these gaps through policy, awareness, and innovation, Saudi Arabia can ensure safer food packaging practices that align with global health and sustainability goals.

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Appendices

The survey

Dear Participant,

Thank you for taking the time to complete this questionnaire.

This survey is part of an academic research project titled "**Health, Safety, and Environmental Aspects of plastic used for food applications.**" The objective of this study is to assess public awareness of the potential risks associated with plastic materials used for food (Daily Usage, Packaging and Storage) considering the compliance with regulatory standers such Saudi Food & Drug Authority, ISO and international health, safety, and environmental standards.

Your responses will be treated with complete confidentiality and used solely for academic purposes. Participation is voluntary and you may withdraw at any time.

Thank you for your valuable input.

Sincerely,

Section 1: Demographic Information

1. **Gender:**

☐ Male ☐ Female ☐ Prefer not to say

2. **Age Group:**

☐ Under 18 ☐ 18–30 ☐ 31–45 ☐ 46–60 ☐ Over 60

3. **Field of Work or Study:**

☐ Petrochemical Sector ☐ Petrol Sector ☐ Safety, Health & Environment

☐ Government Sector ☐ Private Sector ☐ Student ☐ Unemployed

☐ Other (please specify): _____

Section 2: Main Questionnaire

Please indicate your level of agreement with the following statements:

1. I always check the type of plastic used in food packaging.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
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2. I believe some plastic types can cause a health issue when used with food.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
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3. I prefer buying food products that are not packed in plastic.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
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4. I am familiar with the plastic identification codes (e.g., PET, HDPE).

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
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5. I avoid heating food in plastic containers.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
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6. Plastic use in the food industry is adequately regulate by authorities.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
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7. I believe companies following regulatory and international standards in plastic use.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
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8. There are eco-friendly alternatives to plastic in food packaging.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
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9. Plastic food waste negatively affects the environment.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
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10. I prefer using biodegradable containers over traditional plastics.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
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11. I always use reusable plastic items in my daily life.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
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12. There is insufficient awareness about the health risks of plastic food use.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
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13. Government agencies are actively working to reduce harmful plastic usage.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
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14. I care about knowing the industrial source of the plastic in food packaging.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
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15. I support the implementation of laws limiting plastic use in food products.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
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Section 3: Open-Ended Questions

1. In your opinion, what are the main health risks related to the use of plastic in food packaging?

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2. What recommendations would you suggest to improve the safety, health and environmental standards in plastic use for food?

.....
