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Assessing the future of food security under trade and production risks in the United Arab Emirates

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Abstract

Contemporary agrifood systems increasingly depend on global trade and value chains. While these connections improve food access, they also increase exposure to geopolitical conflict, export restrictions, market volatility, and supply-chain disruptions, particularly in import-dependent countries. The UAE exemplifies this exposure because it meets most of its cereal demand through imports, making its cereal security sensitive to instability in global markets. Given this exposure, we applied a stakeholder-informed exploratory scenario-planning approach to explore plausible futures for UAE cereal security through 2050. The scenario-planning process began with an initial review of relevant academic publications and official reports. Thirty-five stakeholders then participated in a structured online survey, an online driver-sorting exercise, and a validation workshop. Responses informed driver assessment, system mapping, and scenario development. Workshop participants then refined the scenarios and identified desirable futures and potential strategies. The analysis initially identified 85 drivers, which were refined into 30 distinct drivers. Global trade stability and domestic cereal production capacity received the highest importance and uncertainty ratings and formed the axes of the scenario matrix. Their combination produced four plausible scenarios: Vulnerable Dependence, System Shock, Adaptive Sufficiency, and Strategic Surplus. The Strategic Surplus scenario was stakeholders preferred future for UAE cereal security. Progress toward this future requires expanding water-efficient domestic production and diversifying import sources and routes. More broadly, the findings suggest that arid, import-dependent regions require integrated cereal resilience strategies combining water-efficient production, agricultural research and innovation, trade diversification, and stronger coordination across the cereal supply chain.

Keywords Food systems, International trade, Value chains, Precision agriculture, Scenario planning



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1 Introduction

Global food systems are evolving rapidly in response to changing consumer preferences, advances in agricultural technology, demographic shifts, climate change, globalization, and emerging political, economic, and environmental pressures. Until the mid-twentieth century, a supply-driven or self-sufficiency approach, in which domestic production was expected to meet national food demand, remained a prominent national food-security strategy in many countries [18, 79]. However, increasing food demand in countries with limited agricultural capacity, combined with surplus production elsewhere, has encouraged a shift toward food self-reliance. This transition reflects the growing integration of national food systems into global markets and trade networks. Food self-reliance combines domestic production with international trade, often drawing on comparative advantage, and has become an important approach to national food security [13, 18, 63]. Over the past five decades, global food trade has grown substantially in both volume and economic value [16, 17, 31], with approximately 80% of the global population now depending, at least partly, on international trade to meet their food demand [56, 79].

Within the globalized food system, exporting countries distribute surplus production, while importing countries use trade to address imbalances between national demand and domestic supply [79, 80, 85]. Reliance on global trade, however, heightens exposure to external risks, including supply chain disruptions, changes in the trade policies of exporting countries, and geopolitical tensions [14, 60, 80]. When these risks coincide with limited domestic production due to high costs and scarce resources, vulnerability to food insecurity increases [74, 77]. In these contexts, ensuring food security requires the proactive assessment of alternative futures and the identification of targeted policy responses.

The Gulf States, and the United Arab Emirates in particular, illustrate this structural dependence. The UAE ranked 23rd out of 113 countries in the 2022 Global Food Security Index [69]. Yet the country imports most of its food, with estimates ranging from 80% to over 90% [32, 35]. Its dependence is even higher for cereals. Cereal self-sufficiency remains below 2%, meaning that imports meet over 98% of national cereal demand [65]. This dependence is particularly consequential because wheat, rice, and maize are major sources of dietary energy and protein [76, 83]. Cereals account for more than one-third of dietary energy and protein intake and are identified as priority commodities in national food-security planning [50, 54, 67], UAE [71]. This creates a structural tension between heavy dependence on external markets and ecologically constrained domestic production. The high import reliance also increases the country's exposure to external shocks. The 2007–2008 global food crisis, COVID-19-related supply-chain disruptions, and export restrictions by major food-exporting countries have revealed structural vulnerabilities in the UAE food system [32, 33, 48, 50]. Beyond supply stability, cereal security in the UAE has direct implications for household food access, price volatility, and social resilience in a highly import-dependent society. It is therefore a critical issue at the intersection of food systems, governance, and human wellbeing.

In response to uncertainty in global trade, the UAE has invested substantially in domestic food production, including the adoption of advanced technologies. These efforts to expand domestic production reflect growing concern about import dependence and a desire to reduce exposure to global market volatility [8, 53]. However, expanding production under arid and saline conditions requires substantial water and

other resources. Agriculture is estimated to account for nearly 70% of the country's annual water use, and this places more pressure on already scarce water resources [21, 43]. Despite policy efforts to transform the food system, substantial uncertainties persist regarding both domestic supply capacity and global market stability. It therefore remains unclear whether existing strategies can ensure long-term cereal security.

These combined pressures underscore the need for proactive, futures-oriented policy analysis. Conventional planning approaches remain important but can be constrained by path dependence, limiting the exploration and consideration of alternative futures and adaptive responses to these complex cereal security challenges. Futures-oriented methods provide valuable tools for assessing how global and domestic conditions may evolve over time. Scenario-based analysis, in particular, supports the exploration of plausible future developments, the identification of emerging risks and opportunities, and the clarification of strategic options for strengthening cereal resilience. Despite growing concern about food system vulnerability in the UAE, few studies have applied exploratory scenario-based analysis to examine the long-term resilience of cereal security under conditions of global and domestic uncertainty.

This study addresses this gap by examining how future developments may affect cereal security in the UAE. Three objectives guide the analysis: first, to identify the key drivers and critical uncertainties influencing the future of cereal supply; second, to develop plausible scenarios for the evolution of cereal security; and third, to assess and identify strategies that could enhance long-term resilience. An exploratory scenario planning approach is employed because it is particularly well-suited to contexts characterized by high uncertainty, cross-sectoral interdependencies, and long planning horizons. By considering multiple plausible futures, the approach helps identify vulnerabilities, emerging risks, and strategic options for strengthening cereal security in the UAE.

2 Methods

2.1 Exploratory scenario planning

Exploratory scenario planning is an analytical method used to examine alternative future trajectories in contexts characterized by high uncertainty and systemic complexity. This approach enables structured analysis of how interacting drivers of change may evolve when future outcomes are influenced by factors outside direct control. It involves identifying key drivers and critical uncertainties, developing multiple internally consistent and plausible scenarios, and presenting these scenarios through coherent narratives. These narratives facilitate comparison across alternative futures and support strategic thinking about long-term system change [27, 59, 74]. Unlike forecasting, or normative pathway approaches, exploratory scenario planning does not seek to predict a single future or prescribe a preferred pathway. Instead, it explores several plausible futures to reveal how uncertainty shapes strategic choices [25, 62].

The method has been widely used across business and economics [70], ecology [49], and food security [39]. Its applications range from narrative-based exploration of alternative futures to informing decision-making when paired with backcasting and visioning [15, 39, 40]. Scenario planning is commonly used in a participatory setting, though expert-based approaches are appropriate when participation is limited or specialized knowledge is required [55, 59]. A stakeholder-informed, expert-based approach was considered appropriate given the technical complexity, geopolitical sensitivity, and

cross-sectoral nature of cereal security in the UAE. While the method is often applied at broader food-system or landscape scales, it can also generate actionable insights for specific commodities in highly import-dependent contexts.

In this study, stakeholder-informed, expert-based exploratory scenario planning was used to identify drivers of change, critical uncertainties, scenario axes, and narrative storylines. Drivers of change are social, economic, political, technological, and environmental factors that shape system dynamics over time. These drivers were mapped to show how they interact and collectively influence cereal security in the UAE. A causal loop diagram was constructed to visualize these relationships and to identify reinforcing and balancing feedback mechanisms within the system [19, 30]. Drivers exhibiting both high uncertainty and high potential impact were identified as critical uncertainties [41, 57]. Two critical uncertainties were selected and positioned along two intersecting axes, generating four quadrants, each representing a distinct plausible future. Scenario axes were defined, the scenario matrix was developed, and coherent narrative storylines were constructed for each quadrant.

2.2 Study area

The UAE had an estimated population of 10.48 million in 2023 [84]. The country is a high-income economy and one of the most food-secure nations globally [69]. Oil, trade, and hospitality are major sectors of the economy, while agriculture contributes less than 2% to GDP [32, 33, 48]. Agricultural land accounts for less than 6% of total land area, representing a decline of 8% over the past two decades [23, 73, 84]. Despite this decline, domestic food production has improved since the adoption of the National Food Security Strategy in 2018, particularly in the vegetable, dairy, and beef sectors. Domestic cucumber production, for example, increased by approximately 70% between 2018 and 2022 [50]. Cereal production, however, remains negligible [50]. The UAE relies almost entirely on global imports and offshore production to meet cereal demand [35]. Offshore production refers to agricultural production managed by UAE-based companies on farmland abroad, including in Europe, the United States, and Africa. Over 85% of national grain supply is sourced from global trade [35]. Cereals are central to food security in the UAE and are consumed across a wide range of products, including bread, pastries, and other processed grain-based foods. Tandoori and Arabic breads are among the most popular wheat-based breads [34, 50]. Beyond nutrition, cereals hold cultural significance in Emirati cuisine, most notably in the preparation of "harees." Demand for cereals has grown steadily, driven by economic expansion, a growing tourism sector, and an increasingly diverse consumer population [28, 35].

2.3 Study design and analysis

This study employed a stakeholder-informed exploratory scenario planning approach to examine alternative future trajectories of cereal security in the UAE under conditions of high uncertainty and systemic complexity. The method was selected to identify key drivers of change, critical uncertainties, and strategic options relevant to long-term cereal security.

Prior to the scenario development process, an initial, contextual review of academic publications and official reports was conducted to develop an understanding of cereal security in the UAE and to identify relevant stakeholders, major actor groups, and key

drivers shaping cereal supply. Insights from this review informed an initial stakeholder mapping through which 69 relevant stakeholders were identified across farming, agri-food production, trade, research, and policy domains. Of these, 35 stakeholders representing institutions across these sectors participated in and completed the structured survey. The 35 stakeholders represented diverse sectoral perspectives, and the number of participants was comparable with other cases of exploratory scenario analysis [39–41]. Scenario development and analysis followed a three-step iterative process combining structured data collection, system analysis, and stakeholder validation.

2.3.1 Step 1: driver identification and system mapping

A structured survey was administered through Google Forms to all 35 participants to identify drivers of change influencing cereal security in the UAE. Participants provided insights into past, present, and anticipated future drivers shaping cereal security. These inputs informed a system analysis in which interactions among identified drivers were mapped and a causal loop diagram (CLD) was developed to visualize reinforcing and balancing feedback mechanisms within the cereal system. Positive causal links were represented by blue arrows and plus signs, indicating that the connected variables change in the same direction. Negative causal links were represented by red arrows and minus signs, indicating that the variables change in opposite directions. Feedback loops composed of these links were interpreted as reinforcing when their net effects amplified an initial change and as balancing when their net effects counteracted it. The diagram was collaboratively constructed by researchers, educators, and technical specialists, enabling triangulation of perspectives and strengthening system-level interpretation. This process resulted in the identification of 85 initial drivers of change.

2.3.2 Step 2: driver assessment and scenario construction

The initial set of 85 drivers was reviewed and refined into 30 distinct drivers through thematic grouping, removal of overlaps, and stakeholder validation. These 30 drivers were subsequently assessed according to their importance, uncertainty, and controllability. Importance refers to the degree to which a driver influences cereal security outcomes. Respondents evaluated the importance of each driver using a structured online survey administered through Google Forms. Drivers were rated on a three-point scale ranging from low (1) to strong (3). Low importance represented drivers with limited influence and relevance to cereal security, whereas high importance indicated drivers with substantial historical and anticipated future influence on cereal security outcomes.

A structured sorting exercise was then conducted using the QSoftware platform (Qsoftware.net) to assess the drivers according to their uncertainty and controllability, which was sorted by all participants. Certain drivers were defined as those for which both the nature and direction of change were relatively well established. Uncertain drivers were those expected to influence cereal security but with unclear magnitude or direction of future effects [39, 41]. Controllability referred to the extent to which a driver could be influenced through existing levels of knowledge, technology, policy instruments, institutional capacity, and political commitment. Uncontrollable drivers were those whose effects and influence could not be readily managed within the existing system. The assessment of uncertainty and controllability was conducted using a five-point scale ranging from highly certain (1) to highly uncertain (5).

Results from the importance ranking and the uncertainty and controllability assessments were combined to identify drivers characterized by high uncertainty and high potential influence. A two-step decision rule was used to distinguish scenario-defining uncertainties from potential policy levers. First, uncertainty was treated as the primary classification criterion, consistent with the exploratory scenario planning process [41, 42]. Drivers assessed as highly uncertain were therefore classified as scenario-defining uncertainties. Second, among drivers sharing similar uncertainty ratings, controllability served as the secondary criterion. Drivers assessed as both highly uncertain and largely uncontrollable were prioritized as scenario axes, while those assessed as uncertain but controllable were incorporated into scenario narratives as potential intervention points. This approach ensured that the scenario axes reflected uncontrollable system uncertainties, while controllable drivers were represented as strategic levers available to policymakers.

Based on these criteria, two critical uncertainties were identified and positioned along intersecting axes to create a scenario matrix consisting of four plausible future scenarios. Initial scenario narratives were drafted by the research team, internally reviewed, and then presented at a stakeholder workshop for validation and refinement to improve internal coherence, plausibility, and consistency as alternative development pathways. Narrative storylines were developed for each quadrant, describing how combinations of global and domestic drivers could shape alternative futures of cereal security in the UAE.

2.3.3 Step 3: stakeholder validation and strategy identification

The scenarios were presented and validated in a stakeholder workshop held at the University of Wollongong in Dubai in March 2023, with participants drawn from academia, government, and industry. During the workshop, participants reviewed and refined the scenario narratives, reflected on desirable future conditions for cereal security in the UAE, and identified strategies and innovations that could support progress toward those futures. Participants addressed three guiding questions: the key challenges within the current cereal system, the characteristics of a desirable cereal security future in 2050, and the strategies required to transition from present conditions toward that future.

Stakeholder-proposed strategies were analyzed and categorized into three analytical groups: characteristics of a desirable future cereal security system, aspects of the current system requiring improvement, and strategic interventions and innovations needed to facilitate transition toward the preferred future. The identification of the preferred future scenario emerged through this strategy elicitation process. Following the presentation and discussion of all four scenario narratives, participants individually ranked the scenarios according to their desirability for long-term national cereal security using a structured voting sheet, with rankings aggregated across all participants.

3 Results

3.1 Drivers of change

A total of 85 initial drivers influencing cereal security in the UAE were identified and subsequently consolidated into 30 distinct drivers (Table 1). These drivers span five analytical levels: supply-side variables, trade and market factors, governance and geopolitical conditions, enabling and constraining factors, and risk variables. Approximately 40% of these drivers relate to cereal production. These include supply-side constraints such

Table 1 Critical drivers of cereal security in the UAE by category, uncertainty, and controllability. The first column shows the broader classification and category of important drivers of change. The second column lists the important drivers of cereal security in the UAE. Columns three to six show the degree of certainty and controllability of each driver. Uncertainty reflects the degree to which the future trajectory of a driver is predictable. Controllability reflects the extent to which a driver can be managed through existing knowledge, technology, and policy instruments. *** indicates that the driver falls into that quadrant

Category	Driver	Certain and controllable	Certain and uncontrollable	Uncertain and controllable	Uncertain and uncontrollable
Supply-side	Local cereal production				***
	Investment abroad			***	
	Inadequate storage			***	
	Grain silos at seaports	***			
	Crop value addition			***	
Trade and market	International cereal trade				***
	Import dependency				***
	Import tariff	***			
	Trade restrictions by exporters				***
	Fragmented supply chain			***	
	Diversifying import sources			***	
	Price capping			***	
Governance and geopolitical	Global geopolitical security				***
	Government support			***	
	Diplomatic and trade agreements			***	
	Restructuring food security governance	***			
Enabling and constraining	Actors' collaboration	***			
	Weak research data	***			
	Modernizing agriculture	***			
	Investment in R&D	***			
	Empowering small-scale farmers	***			
	Climate-smart agriculture			***	
	Investment in supply chain management	***			
	Efficient use of resources			***	
	Big data development			***	
	Resource scarcity		***		
Risk and shock	Adverse agro-climatic condition		***		
	Climate change		***		
	Food waste	***			
	Global pandemics	***			

as land and water scarcity, and high production costs linked to desalinated irrigation water (Table 1). Other drivers reflect the broader systemic context within which cereal production and supply operate. Disruptions in global cereal trade emerged as important external drivers shaping cereal availability. Governance conditions, including geopolitical stability, diplomatic relations, and institutional support for agriculture, were identified as enablers of both domestic production and trade-based supply. Risk and shock variables, including climate change represent the most certain and least controllable influences on the system. Collectively, these drivers and their interactions shape the dynamic structure of cereal security in the UAE (Fig. 1).

3.2 System dynamics and critical uncertainties

The 30 drivers assessed as most important by stakeholders (Table 1) informed the development of the causal loop diagram (Fig. 1), which maps the key feedback mechanisms shaping cereal security in the UAE.

3.2.1 Reinforcing and balancing feedback loops

Three reinforcing feedback loops were identified, each representing a distinct pathway through which cereal security in the UAE can be strengthened. The first reinforcing loop (R1) relates to trade and strategic positioning. The UAE's geographic location along global trade routes supports a strong strategic trade position, which strengthens trade links with cereal-exporting regions. Strong trade links facilitate higher import volumes, increasing total cereal supply and strengthening cereal security. Improved cereal security means surplus availability is re-exported to other regions, which in turn reinforces the UAE's strategic trade position and sustains the loop. Value chain efficiency acts as a conditional amplifier within R1: when logistics, processing, and market integration

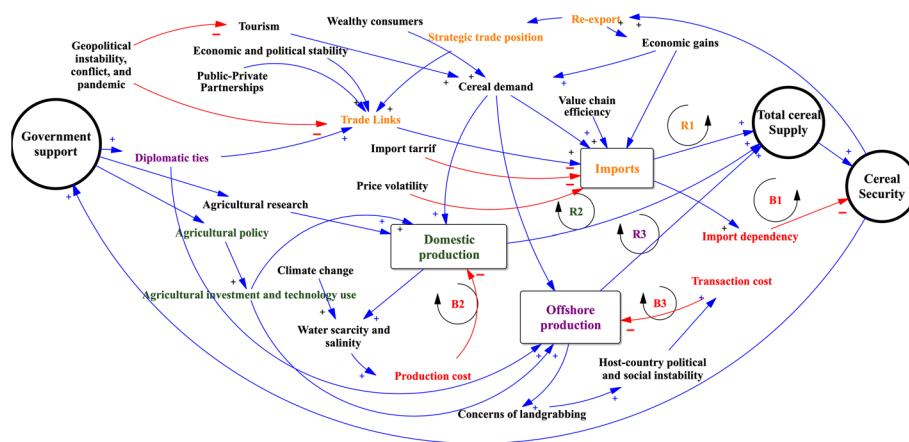


Fig. 1 Causal loop diagram of the cereal security system in the UAE. The diagram depicts three reinforcing feedback loops (R1, R2, R3) and three corresponding balancing feedback loops (B1, B2, B3) shaping cereal security in the UAE. Example reinforcing loop, R1: Strategic trade position → trade links → imports → total cereal supply → cereal security → re-export → strategic trade position. Example balancing loop, B1: Imports → import dependency → cereal security (−) → re-export → strategic trade position → trade links → imports. Node shapes: ○ Circle: nodes shared across multiple feedback loops (cereal security, government support, and total cereal supply); □ Rectangle: the three core supply nodes (imports, domestic production, and offshore production). Loop and pathway-label colours: Orange: R1, the trade-import reinforcing loop; green: R2, the domestic-production reinforcing loop; purple: R3, the offshore-production reinforcing loop; red: B1, B2, and B3, the balancing loops constraining R1, R2, and R3, respectively. Arrow polarity: (+) an increase in the causal variable produces an increase in the affected variable; (−) an increase in the causal variable produces a decrease in the affected variable

function effectively, import costs fall and supply reliability increases improving reinforcing dynamic.

The second reinforcing loop (R2) operates through domestic cereal production. Government support for food security enables the development and implementation of agricultural policies that mobilize agri-investment and technology adoption. Investment in technology and farming systems increases local cereal production, which expands total cereal supply and strengthens cereal security. Stronger cereal security reinforces the political justification for continued government support, sustaining the domestic production pathway.

The third reinforcing loop (R3) operates through offshore cereal production. Government support strengthens diplomatic ties with cereal-producing countries, enabling UAE-based agribusiness firms to establish and expand offshore production operations. Offshore production contributes directly to total cereal supply, strengthening cereal security. Stronger cereal security reinforces government support for continued offshore investment and diplomatic engagement, sustaining the offshore production pathway and completing the loop.

In addition to the reinforcing loop, three balancing feedback loops were identified, each constraining a corresponding reinforcing loop under adverse conditions. The first balancing loop (B1) constrains R1 through import dependency. Increased imports increase import dependency, which weakens cereal security by increasing exposure to external supply disruption. Global governance chaos and conflict negatively affect trade links, reducing the reliability and volume of cereal imports. Reduced imports reduce total cereal supply and weaken cereal security. Weakened cereal security reduces re-export activity, which diminishes the UAE's strategic trade position and further undermines the trade relationships that sustain import reliability. B1 therefore constrains the reinforcing dynamic of R1 and drives the system toward supply contraction under conditions of global instability.

The second balancing loop (B2) constrains R2. Increased domestic cereal production places additional pressure on scarce fresh water and intensifies soil salinity, which raises the cost of domestic cereal production. Elevated production costs limit domestic cereal output, and reduce total cereal supply and then cereal security. Weakened cereal security reduces the political and financial justification for continued government support of agricultural investment and technology adoption, suppressing the domestic production pathway that R2 depends on. B2 therefore constrains R2 through a resource-pressure and climate-driven cost mechanism.

The third balancing loop (B3) constrains R3. Increased offshore cereal production can intensify concerns about land grabbing, contributes to political and social instability in the host countries and raising transaction costs. This then constrain offshore cereal production, reducing the volume of cereal available to the UAE. Reduced offshore output reduces total cereal supply and weakens cereal security. Weakened cereal security reduces government support for offshore investment and weakens diplomatic engagement with host countries. B3 therefore constrains R3 through land governance, transaction cost, and political risk mechanism in which instability in host countries generates the conditions that undermine the diplomatic and investment foundations of the offshore production pathway.

The dominance of these loops shifts with external conditions. Under stable trade, R1 dominates; under sustained policy support, R2 strengthens domestic production; and under active diplomatic engagement, R3 supplements offshore supply. Conversely, import dependency and global governance disruption, resource pressure and climate stress, and concerns of land grabbing and host country instabilities strengthen B1, B2, and B3 respectively, suppressing their corresponding reinforcing loops. This shift in loop dominance is the core dynamic mechanism distinguishing the four scenarios presented in this study (Fig. 1).

3.3 Uncertainties and scenarios of the future of cereal security

Among the 30 drivers ranked for important, five emerged as both highly uncertain and uncontrollable (Table 1). These drivers, namely global geopolitical security, the stability of cereal supply and trade, import dependency, the performance of domestic or onshore and offshore production, and export restrictions imposed by sending regions, are uncertain and also largely uncontrollable in terms of how they may evolve in the future. Collectively, they fall into two overarching categories: global trade dynamics and domestic production capacity. These two categories formed the basis for the scenario axes used to structure the alternative futures (Fig. 2).

Using these key uncertainties and the system dynamics mapped in the causal loop diagram (Fig. 1), four scenarios were developed based on two scenario logics: global trade conditions and domestic production performance (Fig. 2). The four scenarios, Vulnerable Dependence, System Shock, Adaptive Sufficiency, and Strategic Surplus, each reflect a distinct combination of global trade stability and domestic production capacity,

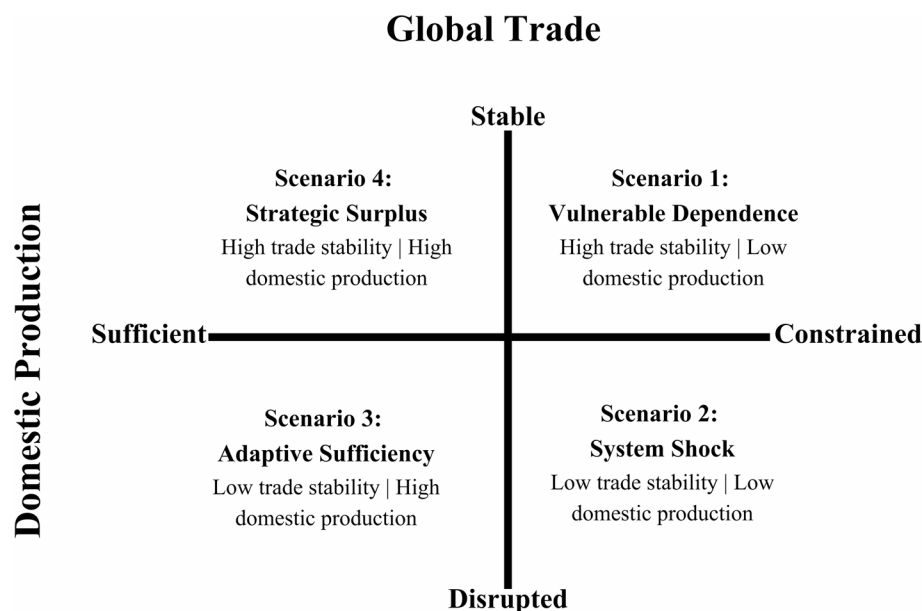


Fig. 2 Scenario axes and logic for future cereal security in the UAE. The scenario framework is structured along two critical uncertainties. The horizontal axis represents domestic cereal production capacity, ranging from sufficient domestic production to no or ceased domestic production with full reliance on imports. The vertical axis represents the stability of global cereal supply, ranging from stable and reliable international trade to disrupted and unstable global supply. Based on these axes, four scenarios are identified: *Vulnerable Dependence* (low domestic production and stable global trade), *System Shock* (low domestic production and disrupted global supply), *Adaptive Sufficiency* (high domestic production and disrupted global supply), and *Strategic Surplus* (high domestic production combined with stable and surplus global supply)

Table 2 Cross-scenario comparison of uncertain drivers and cereal security outcomes. The table compares how the five highly uncertain and largely uncontrollable drivers identified in Table 1 manifest across the four cereal security scenarios, and what cereal security outcomes result under each scenario's conditions. Uncertain driver rows describe the prevailing state of each driver as an external condition shaping the scenario. Cereal security outcome rows describe the consequences of those driver configurations for cereal availability, price stability, and overall cereal security in the UAE. Scenarios represent distinct configurations of global trade stability and domestic production capacity rather than predictions of future states

Dimension	Vulnerable dependence	System shock	Adaptive sufficiency	Strategic surplus
<i>Uncertain drivers</i>				
Geopolitical security	Stable; open trade policies and bilateral agreements hold	Severely disrupted; conflicts trigger export restrictions	Moderately unstable; international trade unreliable	Stable; bilateral agreements support diversified sourcing
International cereal trade	High stability; surplus in exporting regions ensures consistent imports	Severely disrupted; export bans and supply chain failures	Thin and unreliable; reduced global supply drives domestic substitution	Stable with global surplus; complements UAE domestic production gains
Import dependency	Very high; demand met almost entirely through imports	Critical; import collapse causes shortages with no domestic buffer	Declining as domestic production expands; exposure reduced	Strategically managed; domestic production and diversified sourcing buffer dependency
Domestic and offshore production	Both negligible; offshore disrupted by host country instability	Both absent; no production buffer available	Domestic production expand through technology and policy support; offshore limited	Both performing at high levels; supply independent of trade conditions
Trade restrictions by exporters	Low risk; diversified suppliers limit exposure	Decisive trigger; directly collapses import volumes	Moderate; partially offset by domestic production	Low risk; bilateral agreements and domestic capacity
<i>Cereal security outcomes</i>				
Cereal availability	Adequate; entirely import-dependent; vulnerable to interruption	Severely reduced; immediate shortages; food availability strained	Adequate; domestic production supplements reduced imports	High; surplus available for re-export; UAE a regional distribution hub
Price stability	Stable normally; vulnerable to increase	Severely unstable; prices rise as availability declines	Moderate; partially insulated through domestic supply	Stable and declining as availability increases and import costs reduce
Cereal security	Fragile; adequate under stability but highly exposed to external shocks	Critical; severely compromised with no alternative production	Conditional; maintained through domestic production but climate sensitive	Robust; achieved through trade, domestic, and offshore supply

producing different levels of cereal security, exposure to shocks, and opportunities for resilience. The five uncertain drivers manifest differently across the four scenarios (Table 2), and the scenarios and associated narratives are presented below.

3.4 Scenario narratives

3.4.1 Scenario 1: vulnerable dependence

This scenario is characterized by the dominance of the trade-import reinforcing loop (R1), where stable global trade conditions maintain import reliability and cereal availability. Balancing loops related to domestic production constraints and offshore risk persist but do not exert big influence.

Cereal imports from multiple supplier countries ensure a consistent supply that meets national demand. The UAE ceased cereal cultivation because of soil salinity, limited irrigation water, and resource constraints, redirecting national priorities toward high-value

crops such as fruits and vegetables. Offshore production fails to offset this deficit, as political instability in host countries disrupts operations and restricts available volumes. Despite the lack of domestic production, the UAE secures adequate cereal supply through international markets. Advances in agricultural biotechnology have increased yields in major exporting regions, resulting in surplus cereal available for trade. The UAE's political stability, robust diplomatic relations, and economic strength facilitate access to diverse suppliers, allowing demand to be met through bilateral and multilateral agreements. Collaboration among private companies, multinational firms, and government agencies ensures steady import flows. However, this approach produces strong import dependency, making the country vulnerable to external shocks. Risks include global supply fluctuations, export restrictions, and political disruptions in supplier countries, heightened by declining global reserves and increasing politicization of food trade.

In terms of driver activation, geopolitical stability, value chain efficiency, and diplomatic ties are the dominant active drivers sustaining cereal availability. Domestic agricultural investment, agri-research, and technology adoption remain suppressed, as import reliability reduces the urgency for production-based alternatives. Domestic production, agricultural investment, and technology adoption remain weak, leaving the system structurally unprepared for disruptions to supply.

3.4.2 Scenario 2: system shock

This scenario represents a fundamental shift in loop dominance, in which the import dependency intensified by global disruption balancing loop (B1), and the climate-cost balancing loop (B2) override the trade-import reinforcing dynamics that sustain cereal availability under stable conditions, collapsing the system toward a low-supply, high-vulnerability state.

The UAE no longer grows cereal crops due to persistent soil salinity, limited irrigation water, and high water demands of cereal farming. National priorities have shifted toward fruits and vegetables that require fewer resources and provide higher economic returns. Offshore production does not offset this decline, as political and social instability in host countries disrupts farming and limits available crop volumes. The UAE cannot rely on global markets to fill the supply gap. Global cereal production declines due to climate impacts, political tensions, and reduced productivity in major exporting regions. Exporting countries impose trade restrictions, and supply chains are disrupted by conflicts, economic shocks, and global crises. Cereal imports fall sharply, availability contracts, prices rise, and the food system becomes increasingly strained. Government agencies and private actors play a central role in managing scarcity and maintaining basic supply levels, but the country remains at risk of long-lasting disruptions.

In terms of driver activation, global governance chaos, export restrictions, price volatility, and climate-induced productivity decline are simultaneously active, triggering balancing loop dominance. Import dependency, manageable under stable conditions, becomes the primary vulnerability. Domestic investment and the agri-research to technology adoption to farmer empowerment chain were never activated in prior periods, leaving no compensating production pathway. Weak actor linkages prevent any rapid domestic supply response, amplifying shock severity.

3.4.3 Scenario 3: adaptive sufficiency

This scenario is based on the domestic production reinforcing loop (R2), in which sustained policy support, agricultural investment, and technology adoption progressively strengthen domestic cereal output, partially compensating for the suppression of trade-dependent loops under global market instability, while balancing loops linked to water scarcity, high production costs, and weak actor linkages remain active constraints.

Global cereal supply is thin and international trade unreliable, limiting the UAE's ability to import from major exporters. The government responds by prioritising local cereal production and encouraging participation from smallholder farmers and private investors, aligning with the national food security strategy. With sustained policy support, the UAE adopts advanced technologies including precision farming, improved irrigation management, and modern seed research. These innovations raise cereal yields and improve resource efficiency. Agricultural research institutions contribute by developing enhanced seed varieties and improved farming systems. As domestic production expands, the UAE becomes more capable of meeting cereal needs for food, livestock feed, and industrial uses. Despite this progress, vulnerabilities persist. Domestic production remains sensitive to climate change, resource depletion, and high production costs linked to desalinated water. Rising demand may outpace domestic supply in the long term, requiring continuous investment and adaptation.

In terms of driver activation, agri-policy support, agricultural investment, and precision agriculture are the dominant active drivers collectively activating R2. The agri-research to technology adoption to farmer empowerment interdependency is the most consequential activated chain, translating research investment into productive output through strengthened actor linkages. High production costs linked to desalinated water remain a constraining driver.

3.4.4 Scenario 4: strategic surplus

This scenario reflects the co-dominance of all three reinforcing loops, the trade-import loop (R1), the domestic production loop (R2), and the offshore production loop (R3), operating simultaneously and mutually amplifying one another, such that no single balancing loop achieves systemic dominance under normal operating conditions, though B1, B2, and B3 remain present and require active management.

The UAE invests in agricultural technology and cereal varieties suited to local conditions, aligned with the National Food Security Strategy 2051. Small-scale farmers, private investors, and national institutions contribute to expanding domestic cultivation. Precision farming, advanced production systems, and biotechnology drive increases in domestic output, achieving secure cereal self-sufficiency by 2050. Simultaneously, advances in crop genetics and global productivity generate surplus cereal supplies in major exporting countries, complementing domestic gains and ensuring stable, affordable availability. The UAE leverages its geographic position, infrastructure, and political stability to become a regional distribution hub for cereals in the Middle East and North Africa. Increased availability lowers prices and stimulates growth in cereal-based industries, strengthening economic performance. Sustaining these gains requires ongoing investment and oversight. Productivity improvements must align with environmental limits, and local producers may face challenges from global surpluses and market dumping.

In terms of driver activation, all three reinforcing loop driver clusters are simultaneously operative: the trade cluster comprising geopolitical stability, diplomatic ties, and value chain efficiency; the domestic production cluster comprising agri-research, biotechnology, precision farming, and farmer empowerment; and the offshore production cluster comprising diplomatic engagement, offshore investment, and host country stability. The agri-research to technology adoption to farmer empowerment interdependency is fully activated and generating system-wide returns. Export restrictions and geopolitical instability remain risk drivers but are effectively buffered through diversification and domestic production capacity.

3.5 Desired future and intervention strategies in cereal security

Stakeholders consistently identified the Strategic Surplus scenario as the most desirable long-term outcome for cereal security in the UAE. This scenario envisions the establishment of a robust and diversified cereal supply system that integrates expanded domestic production, geographically diversified offshore investments, and stable international trade relations. A key component is diversifying offshore production, with UAE-based companies cultivating cereals and related crops across multiple regions to mitigate exposure to localized shocks. Established firms such as Al Dahra, Al Ghurair Foods, and Al Jenaan are regarded as anchor actors in this strategy, complemented by the entry of new private companies investing in politically stable and suitable countries.

Domestically, stakeholders envisioned an increase in cereal production enabled by advanced agricultural technologies. The Mleiha wheat farm in Sharjah was frequently cited as a case study, demonstrating the technical feasibility of wheat cultivation under desert conditions through precision agriculture. Building on this example, stakeholders envisioned the development of multiple high-technology cereal farms across the emirates, supported by climate-adapted crop varieties, controlled environment production systems, and desalination powered by renewable energy. These domestic and offshore production investments are supported by expanded storage infrastructure, enhanced processing capacity, and more efficient logistics and supply chains. Collectively, these measures are identified to position the UAE as a regional hub for cereal distribution and to strengthen resilience through a diversified, adaptive supply system capable of responding to global disruptions.

Stakeholders identified several strategies they considered necessary to achieve the desired future state. Key priorities include expanding domestic cereal production through precision agriculture, improved seeds, controlled-environment systems, and investment in arid-land research. Offshore diversification across continents and crop types is essential to reduce geographic concentration risk. Strengthening collaboration among research institutions, extension services, private agribusiness, and market actors will accelerate innovation adoption. Additional measures include improving water use efficiency, expanding national grain reserves, and upgrading storage and processing infrastructure. Trade diversification, enhanced diplomatic engagement, and investment in logistics and port capacity are important for maintaining stable supply channels. Providing technical and financial support to farmers and proxy producers, along with better knowledge dissemination, will help sustain domestic production under changing conditions. Together, these strategies offer a robust pathway to advance cereal security and achieve the Strategic Surplus goal.

4 Discussion

This study applied an exploratory scenario planning approach, combining stakeholder workshops and structured expert surveys, to examine how cereal security in the UAE could evolve toward 2050 under conditions of uncertainty. By analysing system dynamics, key drivers of change, and critical uncertainties, four plausible future trajectories were developed, structured around two core scenario logics: domestic cereal production and global trade stability. While all four scenarios represent plausible futures, stakeholder assessments converged on Strategic Surplus as the most desirable configuration. Although the analysis focuses on cereals, the findings may provide broader analytical insights for national food security given that cereals account for more than one quarter of total caloric intake in the UAE [28, 29]. The study may also generate transferable insights for Gulf states that share similar structural characteristics, including low cereal self-sufficiency and high dependence on imports [36, 43, 58, 76].

Gulf states share structural food security constraints but have responded differently. Saudi Arabia pursued domestic farming combined with overseas agricultural investment, scaling back domestic wheat production due to groundwater depletion before turning to farmland investments abroad, following a path resembling Adaptive Sufficiency [9, 51, 82]. Qatar's experience during the 2017 blockade, when key supply routes were abruptly cut, illustrates a sudden supply crisis comparable to System Shock, prompting rapid diversification of trade routes and acceleration of domestic production despite significant resource costs [6, 9, 51]. Kuwait and Bahrain continue to rely heavily on imports supported by oil wealth and stockpiling, a position resembling Vulnerable Dependence where financial capacity mitigates but does not remove exposure to supply disruptions [12, 20, 52, 82]. These comparisons suggest that the four scenarios developed in this study are not unique to the UAE but may also represent strategic pathways that other Gulf states occupy or transition between, depending on their resource endowments, fiscal capacity, and policy choices [12, 51, 52, 82].

Three important patterns emerge from the scenario analysis. First, relying heavily on imports is manageable when global trade is stable, but becomes a serious risk when trade is disrupted. Second, investing in agricultural research and adopting suitable technologies for the dryland farming, such as precision farming can help countries build the capacity to produce food domestically. Third, geopolitical instability can rapidly undermine multiple supply pathways to access to food crops simultaneously. Thus, improving cereal security in UAE requires addressing several drivers together and sustaining those efforts over the long term.

4.1 The future of cereal security: embracing a diverse approach

The four scenarios illustrate how different configurations of reinforcing and balancing feedback mechanisms shape alternative futures of cereal security in the UAE. Collectively, they demonstrate that long-term cereal security depends not on any single supply pathway, but on the capacity to balance uncertainties associated with global trade, domestic production constraints, and geopolitical instability. This finding contributes to ongoing debates in the Gulf region regarding whether food security should rely primarily on upstream investment in domestic production or downstream integration into global cereal value chains [82].

Over the past decade, several Gulf states, including the UAE and Saudi Arabia, reduced or discontinued domestic cereal production due to severe water scarcity, soil salinity, and the high economic cost of cereal cultivation relative to imports [23]. Consequently, cereal demand has increasingly been met through international markets [29, 54, 78]. While this transition reduced pressure on groundwater resources and enabled greater focus on crops with comparative advantage, such as dates [5, 22, 54], it also increased exposure to external shocks associated with trade disruption, geopolitical instability, and export restrictions, dynamics reflected in the Vulnerable Dependence and System Shock scenarios.

To reduce this vulnerability, the UAE has increasingly combined trade-based supply with offshore agricultural investment. Supported by strong diplomatic relations and substantial financial resources, the UAE, alongside Saudi Arabia, has emerged as a major investor in offshore agriculture across Africa, Asia, and Eastern Europe. These investments aim to secure upstream access to cereals and other strategic crops while simultaneously strengthening downstream integration into global processing, logistics, and trading systems. For example, ADQ's acquisition of major stakes in Al Dahra and Louis Dreyfus Company BV has further strengthened the UAE's position within global cereal value chains [2, 34].

However, the resilience of an offshore-oriented cereal system remains uncertain. Global cereal trade is highly concentrated, with a limited number of exporting countries controlling a large share of international supply, increasing vulnerability to geopolitical conflict, export restrictions, and market disruption [47, 48, 64, 80, 83]. The scenario analysis therefore suggests that neither import dependence nor domestic self-sufficiency alone is sufficient to ensure long-term cereal security under conditions of climatic and geopolitical uncertainty. Instead, resilience emerges from a pluralistic self-reliance approach that combines diversified trade relations, strategically distributed offshore production, and selective domestic production supported by technological innovation. This interpretation aligns with earlier analyses of Gulf food security systems [82], and with recent UAE food security policy directions articulated by MOCCA [50].

4.2 Cereal self-sufficiency and self-reliance in future scenarios: strategies

The analysis identifies four complementary strategies for strengthening long-term cereal security in the UAE: expanding domestic production, strengthening offshore production, diversifying import sources, and increasing storage capacity. Together, these strategies reflect broader policy priorities within the UAE [50], regional food security agendas [26, 64, 66], and continuing debates regarding the balance between food self-sufficiency and self-reliance in the Gulf region [82, 83].

Strengthening domestic cereal production remains one important pathway toward greater resilience. Although cereal cultivation in arid environments faces major constraints linked to water scarcity, soil salinity, and production costs, recent technological advances have improved the feasibility of local production under desert conditions. The large-scale cereal farm in Mleiha, supported by precision agriculture, AI-based monitoring systems, and pesticide-free organic practices, illustrates this potential [53, 61]. While current production volumes remain modest relative to national demand, such initiatives demonstrate the possible role of domestic production as a strategic buffer during periods of global supply disruption rather than as a complete replacement for imports.

Expanding this pathway will require continued investment in climate-adapted crop varieties, irrigation efficiency, controlled-environment agriculture, and arid-land agricultural research.

Offshore production constitutes a second strategic pillar. The UAE is among the leading Gulf investors in offshore agriculture, with investments extending across Africa, Asia, Eastern Europe, Australia, and North America [10, 68, 81]. UAE-based companies such as Al Dahra Agriculture, Al Jenaan, and Al Qudra Agriculture operate cereal production systems in countries including Egypt, Sudan, Ethiopia, Romania, Serbia, Australia, and the United States, contributing to UAE supply chains [3, 4, 37, 38, 44]. These investments aim to secure upstream access to cereals while reducing exposure to disruptions in global spot markets. However, the long-term viability of offshore production depends not only on technological capacity and financial investment but also on political stability, diplomatic relations, land governance arrangements, and social legitimacy within host countries. Earlier offshore initiatives faced criticism related to land rights, inequality, and political instability [24, 45], demonstrating that offshore production can itself generate new vulnerabilities and governance challenges.

Diversification of import sources and expansion of storage infrastructure form a third strategic pathway. In response to disruptions associated with the Russia–Ukraine conflict, and COVID-19 pandemic, the UAE expanded cereal sourcing beyond traditional suppliers such as Australia and Canada by increasing imports from India and Eastern Europe [1, 23, 46], UN [75, 84]. India has consequently emerged as one of the UAE's major cereal suppliers [23, 35]. Alongside trade diversification, investments in grain reserves and storage infrastructure have strengthened the country's emergency preparedness capacity. Major actors, including Al-Ghurair and ADQ, operate large storage and logistics facilities at Khalifa Port, Jebel Ali Port, and Fujairah Port, collectively managing a substantial share of cereal imports and reserves [7, 28, 29]. These investments enhance supply flexibility and reduce vulnerability to short-term market disruptions and trade interruptions.

The analysis nevertheless indicates that no single strategy is sufficient on its own. Scenarios dominated primarily by imports remain vulnerable to geopolitical shocks and export restrictions, while domestic production remains constrained by environmental limits and production costs. Similarly, offshore investments are exposed to political instability and governance risks in host countries. The Strategic Surplus scenario therefore does not imply complete cereal independence, but rather the development of a diversified and adaptive supply system in which domestic production, offshore production, trade diversification, and storage capacity complement one another.

Achieving such a system also involves important trade-offs. Expanding domestic cereal production under desert conditions depends heavily on desalination and advanced technological systems, raising concerns regarding long-term environmental sustainability and energy use. Offshore agricultural investments may generate geopolitical tensions, land-right disputes, and resistance from local communities, particularly where large-scale land acquisitions occur in food-insecure regions. In addition, the concentration of imports, storage infrastructure, and offshore investments within a limited number of sovereign-linked agribusiness actors raises governance concerns related to accountability, transparency, and market concentration. During periods of supply disruption, commercial interests may not always align fully with national food security objectives.

These findings suggest that future cereal security in the UAE depends not on maximizing any single pathway, but on maintaining a balanced and flexible combination of domestic production, offshore investment, diversified trade relations, and strategic reserves. From a systems perspective, resilience emerges through diversification and adaptive governance capable of managing the environmental, geopolitical, and economic trade-offs associated with each strategy.

4.3 Agricultural technologies as a leverage to transformation

Stakeholders consistently identified advanced agricultural technologies as a critical leverage point for strengthening cereal security in the UAE by improving domestic production capacity, resource-use efficiency, and coordination across value chain actors. Technologies associated with precision agriculture, including AI-supported monitoring, sensor-based systems, robotics, and data-driven irrigation management, were viewed as particularly important for addressing production constraints under arid conditions while reducing vulnerability to trade-related disruptions. These priorities align closely with national food security strategies aimed at expanding climate-smart and resource-efficient agriculture [54], UAE [71, 72]. Recent initiatives, including the Sharjah cereal farm and emerging controlled-environment farming systems, demonstrate the growing feasibility of technologically supported cereal cultivation under desert conditions [11, 54, 61].

However, stakeholders also emphasized that technological transformation depends not only on innovation itself, but also on stronger linkages among research institutions, extension services, agribusiness actors, and producers, as well as improved access to technical capacity and infrastructure. From a systems perspective, agricultural technologies therefore function not simply as productivity-enhancing tools, but as a broader leverage point capable of strengthening adaptive capacity and supporting the transition toward a more diversified and resilient cereal supply system.

4.4 Policy implications

The findings indicate that future cereal security in the UAE cannot be achieved through reliance on a single supply pathway, whether import dependence or complete domestic self-sufficiency. Instead, the analysis points to a sequenced transition across complementary pathways, structured here into three stages distinguished by time horizon, strategic priority, and responsible actors.

Near-term import diversification and reserve expansion: in the near term, the primary goal is to reduce exposure to acute supply shocks. Diversifying import sources and strengthening storage infrastructure can reduce exposure to disruptions affecting individual suppliers or trade corridors [23, 82]. Responsibility at this stage would be required distributed across government authorities responsible for trade and food security policy, logistics agencies managing storage and distribution infrastructure, importers and commodity traders operating along supply corridors, and other actors in the cereal value chain.

Medium-term domestic scaling and agri-research investment: in the medium term, the goal is to build domestic buffering capacity that reduces structural dependence on imports. Continued investment in domestic production technologies can strengthen local buffering capacity under conditions of global instability [23, 82]. This stage requires

sustained commitment from research organizations and agribusiness firms, supported by government funding and regulatory instruments.

Long-term co-dominance of pathways toward Strategic Surplus: in the long term, the goal is to achieve a stable configuration in which domestic production, offshore investment, and diversified trade operate as co-dominant and mutually reinforcing strategies. Offshore agricultural investments further contribute to supply diversification by strengthening upstream access to cereals and reducing dependence on volatile global spot markets, although these investments remain exposed to geopolitical instability, land governance challenges, and social legitimacy concerns in host countries [24, 45]. The analysis also highlights the importance of governance coordination across government authorities, research organizations, agribusiness firms, and producers to ensure that trade diversification, technological innovation, and infrastructure investments operate as complementary rather than isolated interventions.

5 Limitation of the study

This study applied an expert-based exploratory scenario planning approach to identify the key drivers, critical uncertainties, and plausible future pathways shaping cereal security in the UAE under conditions of climatic, geopolitical, and economic uncertainty. By integrating systems thinking with stakeholder knowledge, it provides a strategic framework or structured basis for exploring alternative futures and identifying policy priorities for strengthening long-term cereal resilience. However, the analysis is qualitative and exploratory rather than predictive, and therefore does not quantify the likelihood of scenarios, their economic costs, or the magnitude of trade-offs associated with alternative policy pathways. Future research could build on this work by integrating scenario planning with quantitative modelling approaches, such as economic modelling, to evaluate the feasibility, costs, and impacts of alternative interventions under different future conditions. Extending the analysis to additional food commodities and conducting comparative studies across Gulf countries would contribute to a broader understanding of food security dynamics across the Gulf region and support more comprehensive regional food security planning.

6 Conclusion

This study used expert-led exploratory scenario planning to identify key drivers, uncertainties, feedback mechanisms, and future pathways shaping cereal security in the UAE. The analysis developed four plausible scenarios representing alternative configurations of trade dependence, domestic production, offshore investment, and system resilience under conditions of climatic, geopolitical, and economic uncertainty. Rather than predicting a single future, the scenarios illustrate how different reinforcing and balancing feedback dynamics may interact to produce distinct cereal security outcomes. The findings show that resilience cannot be achieved through exclusive reliance on either imports or domestic self-sufficiency alone. Instead, long-term cereal security depends on maintaining a diversified and adaptive system that combines resilient trade networks, strategic storage capacity, selective domestic production, offshore agricultural investment, and technological innovation.

The analysis further highlights the importance of activating the agri-research to technology adoption to farmer empowerment pathway as a key enabling condition for

strengthening domestic adaptive capacity under arid conditions. Achieving this transition requires sustained coordination among federal institutions, research organizations, agribusiness actors, and producers to ensure that technological innovation, trade diversification, and infrastructure investments operate as complementary rather than isolated interventions. More broadly, the study demonstrates the value of combining systems thinking and exploratory scenario approaches for understanding food security under deep uncertainty and for identifying pathways capable of strengthening resilience in resource-constrained environments.

The study nevertheless has important limitations. The expert-based approach did not fully capture the perspectives of smallholder farmers, women, lower-income consumers, or host-country communities affected by offshore agricultural investments. Future research should therefore extend this framework through more participatory and inclusive approaches capable of addressing the social equity, legitimacy, and governance dimensions of cereal security transitions alongside their technical and strategic components.

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Author contributions

TSJ: Conceptualization, Methodology, Formal analysis; Writing – original draft. KA: Conceptualization, Methodology, Formal analysis; Writing – review and editing. GG: Writing – review and editing. MJ: Writing – review and editing. TK: Writing – review and editing. BS: Conceptualization, Methodology, Writing – review and editing.

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Data availability

The data that support the findings are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The study received ethical approval from the International Center for Biosaline Agriculture (ICBA) Ethics Committee. During the period in which ethical approval was granted, the ICBA Ethics Committee did not have a system for issuing official ethics approval numbers. All research procedures were conducted in accordance with the ethical guidelines and regulations of the International Center for Biosaline Agriculture and the principles of the Declaration of Helsinki. Participation in this study was voluntary. All respondents were informed about the purpose of the research, assured of anonymity and confidentiality, and provided their informed consent before completing the questionnaire. Participants were given the right to withdraw at any time without any consequences.

Consent for publication

Not applicable.

Competing interests

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