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# Designing a model for analyzing resilience scenarios using structural equation modeling in the sesame industry supply chain of Yazd province

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**Abstract** This study aims to design and evaluate resilience scenarios for the sesame industry supply chain in Yazd Province, focusing on risks arising from economic changes and market volatility, in order to strengthen the resilience and sustainability of this strategic product's supply chain. First, 24 criteria influencing supply chain resilience were identified. Using the fuzzy Delphi method, 12 final criteria were selected. Structural Equation Modeling (SEM) was then employed to analyze the relationships among the resilience factors. Several tests, including coefficient of determination, predictive relevance, and effect size, were used to assess model quality. The analysis is based on expert evaluations of resilience criteria in the sesame supply chain of Yazd Province, collected and refined through fuzzy Delphi and subsequently modeled using SEM. The results show that economic, technical, and organizational factors are prioritized, respectively, in influencing supply chain resilience. The tests confirm strong and significant relationships among the variables, indicating the robustness and predictive power of the proposed model. By integrating fuzzy Delphi for criteria selection with SEM for causal analysis, this study provides a structured framework for assessing and improving resilience in an agricultural supply chain. It offers practical scenarios that enable managers to identify strengths and weaknesses under different simulated conditions, adopt effective strategies, and enhance resilience through valid, up-to-date data and stakeholder collaboration. The proposed approach can be applied as a model for similar industries in Yazd Province and other regions.

**Keywords:** Resilience, Supply Chain, Scenario Design, Prioritization.

## 1 Introduction

The supply chain, as a complex network of processes, people, and resources, plays a vital role in the success and sustainability of various industries. In this regard, the sesame-based industries, as one of the important economic sectors of Yazd Province, face numerous

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challenges, including climate change, market fluctuations, and logistical problems. Supply chain resilience refers to the ability of a supply chain to cope with such challenges and maintain optimal performance under disruptive conditions. Designing models capable of analyzing different resilience scenarios can assist managers and decision-makers in adopting effective strategies to enhance supply chain performance.

In today's global economy, on the one hand, companies strive to gain competitive advantage and ensure long-term survival in the market, while on the other hand, customers seek goods and services that meet their needs. Therefore, supply chain management is considered one of the essential elements for responding to customer demands and achieving sustainable competitive advantage [1]. Chandra and Grabis argue that the supply chain encompasses all stages that directly or indirectly satisfy customer demand. From this perspective, the supply chain is not limited to manufacturers and suppliers, but also includes carriers, wholesalers, retailers, and customers [2].

Moreover, since organizations operate in dynamic and unpredictable environments and cannot avoid disruptions in their supply chains, these chains must be designed in a way that enables them to respond efficiently and effectively to any event and to return to their original state or even a more desirable condition after a disruption [3]. Disruptions are sudden and unexpected breakdowns resulting from various factors such as natural disasters, fires, and loss of critical suppliers, wars, cyberattacks, economic recessions, sanctions, economic shocks, terrorism, and others [4-5]. When such events occur, they can have irreparable consequences for businesses [6]. Under these conditions, the need to design resilient supply chain patterns becomes increasingly evident [7].

The resilience approach in supply chain management is applied with the aim of creating the capability for a supply chain to recover to its initial state or to a new and more desirable condition after the occurrence of disruptions, while avoiding failure states [8]. Furthermore, the nature of a resilient supply chain differs from other supply chains such as lean or agile supply chains and involves specific challenges and difficulties that must be properly identified in order for the chain to remain competitive [9]. Consequently, companies can manage supply chain failures through resilience and continue delivering their products and services to customers [10].

Given the importance of this issue, employee's at all organizational levels should be aware of failures and strive to learn from even minor disruptions within the supply chain. Managers, in turn, should establish an appropriate formal risk management infrastructure by allocating human resources and information resources to specialize management practices and respond to both actual and perceived risks [11]. On the other hand, decision-making problems are often defined under conditions of uncertainty due to limited human knowledge or restricted access of decision-makers to information [12]. In such cases, it is preferable for experts to express their evaluations using linguistic variables, which has led to the application of fuzzy logic [13]. Additionally, experts are usually uncertain when choosing among different linguistic terms to express their opinions; that is, instead of a single membership degree, they consider a range of possible values, for which the fuzzy set approach is employed to address this issue [14].

Considering the above points, one of the strategic industries that has a significant impact on economic growth and employment generation in Yazd Province (Iran) is the sesame products industry. Failure to design resilient supply chains in this industry can lead to irreparable losses for the province during times of economic, political, and social crises. Accordingly, this study aims to achieve competitive advantage in an unstable business environment by selecting scenarios based on factors affecting supply chain resilience in the



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sesame products industry of Yazd Province. This is accomplished by designing a conceptual model based on identified criteria and then validating this model using structural equation modeling (SEM) to cope with climate change and market fluctuations.

Structural equation modeling, as a powerful tool for analyzing relationships among various factors, can help identify and evaluate the mutual effects of these factors on supply chain resilience. In this study, we seek to design a model that analyzes resilience scenarios of the sesame supply chain in Yazd Province using SEM. This model can assist in identifying the strengths and weaknesses of the supply chain and in proposing effective solutions to improve the resilience and sustainability of these industries. Given the importance of sesame as a strategic and valuable product in this region, there is a strong need for a resilient and flexible supply chain capable of withstanding challenges such as climate change, price fluctuations, and logistical issues. Therefore, this topic can serve as a comprehensive research project in the field of supply chain management and resilience in agricultural industries and contribute to improving the performance and sustainability of sesame industries in Yazd Province.

The remainder of the paper is organized as follows. Section 2 presents a literature review to identify the research gap. Section 3 introduces the research modeling based on a mathematical model for selecting appropriate scenarios. Section 4 presents the results of the case study. Finally, Section 5 provides conclusions along with suggestions for future research.

## 2 Literature review

This section reviews previous studies in order to identify the research gap. Zhou et al. [15] proposed an integrated framework for supply chain resilience enablers. A hierarchical model based on the Technology–Organization–Environment (TOE) framework was developed, and interpretive structural modeling (ISM) was used to analyze hierarchical relationships among the enablers. By evaluating driving power and dependence power, a classification was obtained using the MICMAC method. Liu et al. [16] evaluated influencing factors and improvement strategies for resilience in prefabricated construction supply chains from a dynamic capabilities perspective. Structural equation modeling (SEM) was used to identify and confirm relationships among factors affecting resilience, and a system dynamics (SD) model was developed to simulate the dynamic effects of these factors. Ma et al. [17] analyzed factors affecting supply chain resilience based on 622 valid company samples using SEM and fuzzy-set qualitative comparative analysis (fsQCA). Wang et al. [18] assessed factors influencing the resilience of green agricultural product supply chains using an improved Grey–DEMATEL–ISM approach. Based on stakeholder theory and a systematic literature review, 15 influencing factors were identified. DEMATEL and ISM were then used to analyze internal relationships, construct a multi-level hierarchical model, and identify fundamental transmission processes and paths. Ebrahimpour and Farjood Chokami [19] identified and ranked supply chain resilience indicators across four dimensions using the SWARA method in the food industry. They determined resilience indicators in the four dimensions of agility, flexibility, leanness, and robustness through a review of theoretical foundations. The analysis showed that the robustness dimension, with a weight of 0.399, was the most important dimension of supply chain resilience, followed by agility, leanness, and flexibility. Eslami Farsani et al. [20] identified and analyzed supply chain resilience strategies through a systematic literature review. A total of 68 resilience strategies were identified and ultimately classified into three main categories based on their time of application: preventive


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strategies, concurrent strategies, and reactive strategies. Nazarizadeh et al. [21] identified supply chain resilience scenarios for Kaleh Company over a 10-year horizon. This study employed new knowledge-based methods grounded in analytical–exploratory futures studies. Data were collected through semi-structured interviews and questionnaires. Structural analysis using MICMAC software was applied for data analysis, while Scenario Wizard software was used for scenario analysis and development. Based on the results, six key strategic factors influencing the resilience of Kaleh Dairy Company's supply chain were identified: economic, environmental, technological, social, political, and intra-organizational factors. Scenario Wizard results indicated 211 scenarios with low probability, 7 plausible scenarios, and 2 scenarios with high probability of occurrence. Mazroui Nasrabadi [22] developed a model to identify key success factors for supply chain resilience in health tourism using a fuzzy cognitive map approach. This qualitative study was conducted in two stages. In the first stage, key success factors were identified based on the four stages of resilience, and in the second stage, a model was proposed for these factors. Piya et al. [23] analyzed supply chain resilience drivers in the oil and gas industry during the COVID-19 pandemic using an integrated approach. The analysis helped determine the intensity of each driver's impact relative to others and identify drivers with the highest driving power for achieving resilience. Rahimi et al. [24] proposed a supply chain resilience model. Using the fuzzy Delphi method, the most important actions and performance measurement criteria related to resilient supply chains were extracted, and finally, an interpretive structural modeling (ISM) approach was used to present the model.

## 2.1 Research gap

Despite the high importance of supply chain resilience in various industries particularly in agricultural and food sectors limited research has been conducted on designing comprehensive models for analyzing resilience scenarios in the sesame supply chain of Yazd Province. While some studies have addressed general supply chain challenges and resilience, none have specifically focused on analyzing resilience scenarios in sesame supply chains using structural equation modeling. Moreover, many existing studies are limited to identifying factors influencing supply chain resilience and do not examine the complex relationships among these factors and their impacts on supply chain performance.

This gap in the literature highlights the need to develop comprehensive analytical models to better understand the resilience of sesame supply chains in Yazd Province. Additionally, the lack of reliable and up-to-date data on sesame supply chains and their specific challenges especially under crisis conditions can reduce the accuracy and effectiveness of existing models. Therefore, this study aims to fill this gap by proposing an analytical model based on structural equation modeling to analyze resilience scenarios in the sesame supply chain of Yazd Province, thereby enhancing knowledge and improving managerial decision-making in this field.

## 3 Methods

In this study, a comprehensive review of the literature related to resilient supply chains was first conducted, through which the indicators and dimensions of this type of supply chain were identified. Subsequently, these indicators and dimensions were validated using the structural equation modeling (SEM) approach. For this purpose, tests such as the coefficient of determination, predictive relevance, and effect size were employed. By implementing this stage, the relationships among the indicators were identified, and appropriate scenarios for the implementation of a resilient supply chain in the sesame-processing industries were developed.

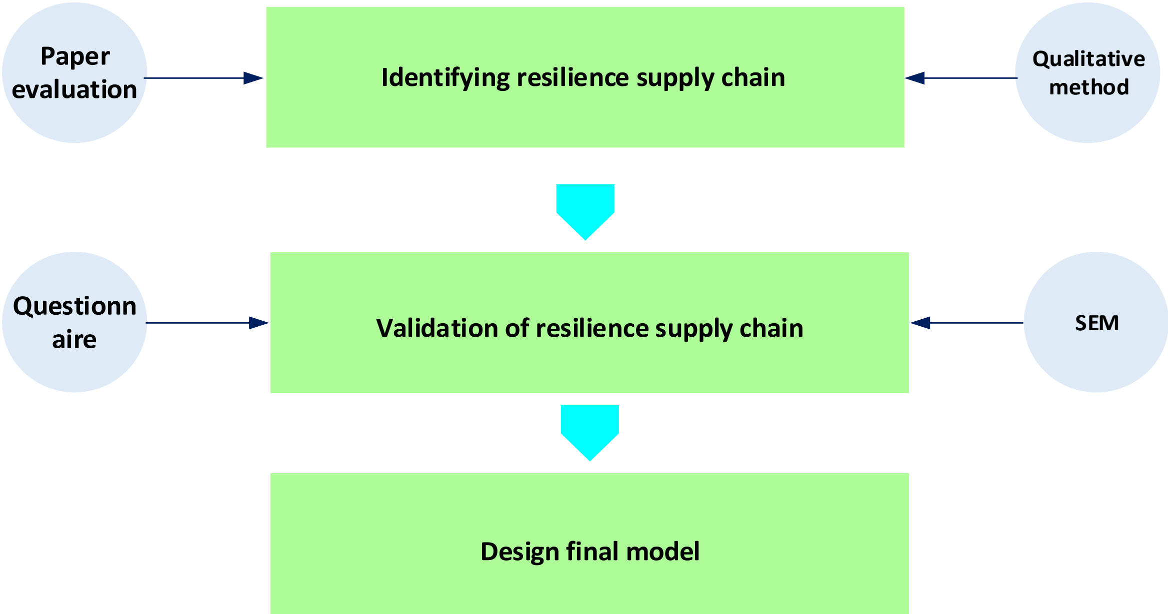


**Fig. 1** Research methodology framework

The statistical population in the first phase of the research includes all published studies in reputable scientific databases related to the factors influencing the success of resilient supply chain management, up to the time of conducting this research. In the second phase of the research, the statistical population consists of active professors in the field of supply chain management and active managers in the sesame products industry in Yazd province, from which a sample will be selected using a purposive judgment sampling method.

## 4 Results

At this stage, a questionnaire containing 24 criteria affecting supply chain resilience, identified through a meta-synthesis approach from the literature, was provided to the expert group members and they were asked to express their opinion on each criterion in the form of verbal variables included in the questionnaire. The initial results of the experts' opinions are given in Table 1.

**Table 1** Results of expert opinions

| Row | Main Dimensions | Criterion | Very Low | Low | Medium | High | Very High |
|---|---|---|---|---|---|---|---|
| 1 | Technical | Supplier Diversity | 0 | 2 | 5 | 13 | 14 |
| 2 | | Product Quality | 3 | 11 | 17 | 2 | 1 |


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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3 | | Risk Management | 0 | 1 | 6 | 14 | 13 |
| 4 | | Transportation Infrastructure | 22 | 11 | 1 | 0 | 0 |
| 5 | | Information Technology | 0 | 0 | 2 | 16 | 16 |
| 6 | | Training and Empowerment | 12 | 8 | 13 | 1 | 0 |
| 7 | | Stakeholder Collaboration | 7 | 6 | 11 | 9 | 1 |
| 8 | | Demand Forecasting | 1 | 1 | 21 | 7 | 4 |
| 9 | Economic | Product Variety | 0 | 1 | 2 | 14 | 17 |
| 10 | | Inventory Management | 0 | 0 | 1 | 11 | 22 |
| 11 | | Environmental Sustainability | 12 | 6 | 6 | 8 | 2 |
| 12 | | Laws and Regulations | 1 | 1 | 9 | 16 | 7 |
| 13 | | Climate Change | 0 | 1 | 3 | 17 | 13 |
| 14 | | Access to Water Resources | 0 | 0 | 4 | 5 | 25 |
| 15 | | Support Systems | 10 | 6 | 7 | 8 | 3 |
| 16 | | Research and Development | 1 | 1 | 6 | 17 | 9 |
| 17 | Organizational | Export Markets | 0 | 2 | 6 | 9 | 17 |
| 18 | | Crisis Management Infrastructure Development | 1 | 0 | 12 | 11 | 10 |
| 19 | | Financing | 0 | 2 | 5 | 16 | 11 |
| 20 | | Market Development | 2 | 5 | 6 | 14 | 7 |
| 21 | | Modern Technologies | 1 | 5 | 8 | 15 | 5 |
| 22 | | Attention to Customer Needs | 5 | 3 | 12 | 8 | 6 |
| 23 | | Distribution Network Development | 1 | 4 | 16 | 5 | 8 |
| 24 | | International Cooperation | 1 | 1 | 8 | 11 | 13 |

Table 1 presents the frequency of experts' opinions regarding the research indicators. In order to fuzzify the numerical values, the responses are first converted into fuzzy numbers based on the corresponding linguistic scale. Subsequently, the fuzzy mean of the obtained scores is calculated, and then, using the following relationship, the fuzzy mean is defuzzified and converted into a crisp value. The results of all fuzzy Delphi calculations are reported in Table 2.

As an example, the fuzzy Delphi calculations for the criterion in Row 1 are as follows: Zero experts assigned a "very low" score, two experts assigned a "low" score, five experts assigned a "medium" score, thirteen experts assigned a "high" score, and fourteen experts assigned a "very high" score. Therefore, the corresponding fuzzy and non-fuzzy (crisp) scores are obtained as follows:

$$Fuzzy\ score = \frac{0\times(0,0,0.25)+2\times(0,0.25,0.5)+5\times(0.25,0.5,0.75)+13\times(0.5,0.75,1)+14\times(0.75,1,1)}{34} = (0.537,0.787,0.934)$$

$$Fuzzy\ score = \frac{0.537+0.787+0.934}{3} = 0.752$$

In this study, the threshold number is considered to be 0.7, and the results show that 20 indicators were confirmed and 18 indicators were eliminated. The results are presented in Table 2.



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**Table 2** Fuzzy Delphi results

| Row | Main Criterion | Criterion | Fuzzy Score | Non-Fuzzy Score | Status |
|---|---|---|---|---|---|
| 1 | Technical | Supplier Diversity | (0.537, 0.787, 0.934) | 0.752 | Confirmed |
| 2 | | Product Quality | (0.176, 0.404, 0.647) | 0.409 | Rejected |
| 3 | | Risk Management | (0.537, 0.787, 0.941) | 0.755 | Confirmed |
| 4 | | Transportation Infrastructure | (0.007, 0.096, 0.346) | 0.15 | Rejected |
| 5 | | Information Technology | (0.603, 0.853, 0.985) | 0.814 | Confirmed |
| 6 | | Training and Empowerment | (0.11, 0.272, 0.522) | 0.301 | Rejected |
| 7 | | Stakeholder Collaboration | (0.235, 0.434, 0.676) | 0.449 | Rejected |
| 8 | | Demand Forecasting | (0.346, 0.588, 0.809) | 0.581 | Rejected |
| 9 | Economic | Product Variety | (0.596, 0.846, 0.971) | 0.804 | Confirmed |
| 10 | | Inventory Management | (0.654, 0.904, 0.993) | 0.85 | Confirmed |
| 11 | | Environmental Sustainability | (0.206, 0.368, 0.603) | 0.392 | Rejected |
| 12 | | Laws and Regulations | (0.456, 0.699, 0.897) | 0.684 | Rejected |
| 13 | | Climate Change | (0.559, 0.809, 0.963) | 0.777 | Confirmed |
| 14 | | Access to Water Resources | (0.654, 0.904, 0.971) | 0.843 | Confirmed |
| 15 | | Support Systems | (0.235, 0.412, 0.64) | 0.429 | Rejected |
| 16 | | Research and Development | (0.493, 0.735, 0.919) | 0.716 | Confirmed |
| 17 | Organizational | Export Markets | (0.551, 0.801, 0.926) | 0.76 | Confirmed |
| 18 | | Crisis Management Infrastructure Development | (0.471, 0.713, 0.89) | 0.691 | Rejected |
| 19 | | Financing | (0.515, 0.765, 0.934) | 0.738 | Confirmed |
| 20 | | Market Development | (0.404, 0.64, 0.838) | 0.627 | Rejected |
| 21 | | Modern Technologies | (0.39, 0.632, 0.846) | 0.623 | Rejected |
| 22 | | Attention to Customer Needs | (0.551, 0.801, 0.926) | 0.76 | Confirmed |
| 23 | | Distribution Network Development | (0.368, 0.61, 0.801) | 0.593 | Rejected |
| 24 | | International Cooperation | (0.507, 0.75, 0.904) | 0.721 | Confirmed |

According to the results in Table 2, out of the 24 identified indicators, 12 indicators related to supply chain resilience were eliminated and 12 indicators were considered for further research.

### 4.1 Results of structural equation modeling for assessing model validity

In this section, structural equation modeling (SEM) is employed to examine the validity of the identified components within the resilience model framework. All relevant tests are implemented on the model, and ultimately, the overall model fit is evaluated. The analysis is presented in two parts: first, the measurement model, and subsequently, the structural model of the research. For this purpose, the assessment of the measurement model in this section is conducted using factor loading and path coefficient tests, reliability tests, convergent validity, and discriminant validity analyses.

### 4.1.1 Factor loadings and path coefficients

The measurement model examines the relationships between latent variables and their corresponding observed indicators (questionnaire items). Figure 2 illustrates the conceptual model of the research in its standardized form, including factor loadings and path coefficients. This figure represents the software output in the estimation mode of path coefficients and coefficients of determination ($R^2$). The values displayed on the paths indicate the path coefficients, the values inside the circles for endogenous variables represent the coefficients of determination, and the values on the arrows of the latent variables denote the factor loadings.

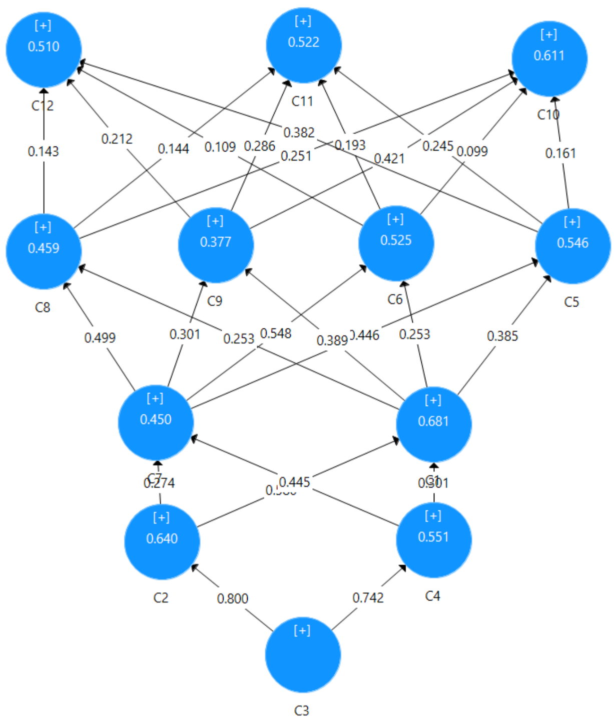


**Fig 2.** Model with factor loading coefficients and path coefficients

The factor loadings of each observed variable on its corresponding latent variable, along with the results of the significance tests, are presented in Table 3. The values of the significance statistic and the standardized factor loadings between the items and the constructs were calculated to be greater than 1.96 and 0.4, respectively, in all cases. Therefore, the relationships between the items and the latent variables are confirmed. Factor loadings above 0.7 (for most items) indicate a good fit between the questionnaire items and the intended constructs. This demonstrates that the designed items were able to adequately and effectively measure the concept of the corresponding constructs.

**Table 3** Factor loadings and significance statistics for the artificial intelligence dimension

| Item | Factor Loading | T-Statistic | Significance Level |
|---|---|---|---|
| Q01 <- C1 | 0.74 | 11.919 | 0 |
| Q02 <- C1 | 0.894 | 33.491 | 0 |
| Q03 <- C1 | 0.856 | 35.149 | 0 |
| Q04 <- C2 | 0.878 | 32.656 | 0 |
| Q05 <- C2 | 0.884 | 34.193 | 0 |
| Q06 <- C2 | 0.689 | 8.14 | 0 |



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| | | | |
|---|---|---|---|
| Q07 <- C3 | 0.871 | 24.404 | 0 |
| Q08 <- C3 | 0.87 | 18.697 | 0 |
| Q09 <- C3 | 0.853 | 27.284 | 0 |
| Q10 <- C4 | 0.871 | 34.714 | 0 |
| Q11 <- C4 | 0.889 | 33.252 | 0 |
| Q12 <- C4 | 0.797 | 15.797 | 0 |
| Q13 <- C5 | 0.886 | 43.051 | 0 |
| Q14 <- C5 | 0.716 | 12.263 | 0 |
| Q15 <- C5 | 0.84 | 24.415 | 0 |
| Q16 <- C6 | 0.845 | 28.738 | 0 |
| Q17 <- C6 | 0.819 | 23.434 | 0 |
| Q18 <- C6 | 0.804 | 22.788 | 0 |
| Q19 <- C7 | 0.791 | 20.076 | 0 |
| Q20 <- C7 | 0.808 | 28.593 | 0 |
| Q21 <- C7 | 0.797 | 26.988 | 0 |
| Q22 <- C8 | 0.8 | 20.962 | 0 |
| Q23 <- C8 | 0.855 | 32.168 | 0 |
| Q24 <- C8 | 0.867 | 36.54 | 0 |
| Q25 <- C9 | 0.835 | 27.12 | 0 |
| Q26 <- C9 | 0.898 | 38.149 | 0 |
| Q27 <- C9 | 0.856 | 35.708 | 0 |
| Q28 <- C10 | 0.806 | 30.899 | 0 |
| Q29 <- C10 | 0.844 | 27.674 | 0 |
| Q30 <- C10 | 0.852 | 34.361 | 0 |
| Q31 <- C11 | 0.836 | 41.873 | 0 |
| Q32 <- C11 | 0.839 | 19.093 | 0 |
| Q33 <- C11 | 0.823 | 21.136 | 0 |
| Q34 <- C12 | 0.849 | 27.759 | 0 |
| Q35 <- C12 | 0.848 | 29.321 | 0 |
| Q36 <- C12 | 0.85 | 22.872 | 0 |

### 4.1.2 Reliability and convergent validity indices

The reflective measurement model is evaluated to confirm the reliability and validity of the model. As shown by the results presented in Table 4, all Cronbach's alpha coefficients are greater than 0.7, composite reliability values exceed 0.7, and the average variance extracted (AVE) values are higher than 0.5.

**Table 4** Cornbrash's Alpha, Composite Reliability (CR), and Convergent Validity (AVE) Indices

| Variable | Cronbach's Alpha | Composite Reliability | Convergent Validity (AVE) | Result |
|---|---|---|---|---|
| C1 | 0.774 | 0.87 | 0.693 | Desirable |

| | | | | |
|---|---|---|---|---|
| C10 | 0.781 | 0.873 | 0.696 | Desirable |
| C11 | 0.781 | 0.872 | 0.694 | Desirable |
| C12 | 0.807 | 0.886 | 0.721 | Desirable |
| C2 | 0.757 | 0.861 | 0.676 | Desirable |
| C3 | 0.831 | 0.899 | 0.748 | Desirable |
| C4 | 0.812 | 0.889 | 0.728 | Desirable |
| C5 | 0.748 | 0.857 | 0.667 | Desirable |
| C6 | 0.762 | 0.863 | 0.677 | Desirable |
| C7 | 0.717 | 0.841 | 0.638 | Desirable |
| C8 | 0.793 | 0.879 | 0.707 | Desirable |
| C9 | 0.829 | 0.898 | 0.745 | Desirable |

### 4.1.3 Discriminant validity

Discriminant validity indicates that variables measuring distinct constructs should not exhibit high levels of association or correlation with one another. In this study, the Fornell–Larcker criterion was employed to assess discriminant validity within the structural equation modeling framework. The results are presented in Table 5. In addition, Table 5 reports the results of the cross-loading test, which demonstrates that the factor loading of each item on its associated latent construct is higher than its loadings on other latent constructs. Therefore, discriminant validity is also confirmed based on cross-factor loadings.

**Table 5** Fornell-Larcker test

| | C1 | C10 | C11 | C12 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 0.832 | | | | | | | | | | | |
| C10 | 0.606 | 0.834 | | | | | | | | | | |
| C11 | 0.592 | 0.68 | 0.833 | | | | | | | | | |
| C12 | 0.671 | 0.657 | 0.78 | 0.849 | | | | | | | | |
| C2 | 0.799 | 0.558 | 0.575 | 0.644 | 0.822 | | | | | | | |
| C3 | 0.723 | 0.571 | 0.597 | 0.663 | 0.8 | 0.865 | | | | | | |
| C4 | 0.724 | 0.572 | 0.645 | 0.623 | 0.73 | 0.742 | 0.853 | | | | | |
| C5 | 0.643 | 0.607 | 0.625 | 0.659 | 0.699 | 0.698 | 0.778 | 0.817 | | | | |
| C6 | 0.569 | 0.58 | 0.605 | 0.58 | 0.61 | 0.613 | 0.652 | 0.733 | 0.823 | | | |
| C7 | 0.578 | 0.579 | 0.621 | 0.607 | 0.598 | 0.595 | 0.644 | 0.669 | 0.694 | 0.799 | | |
| C8 | 0.541 | 0.635 | 0.551 | 0.545 | 0.53 | 0.51 | 0.52 | 0.592 | 0.528 | 0.645 | 0.841 | |
| C9 | 0.563 | 0.702 | 0.603 | 0.555 | 0.487 | 0.504 | 0.565 | 0.533 | 0.545 | 0.525 | 0.56 | 0.863 |

**Table 6** Cross-Loading test

| Item | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q01 | 0.74 | 0.524 | 0.509 | 0.619 | 0.554 | 0.433 | 0.452 | 0.38 | 0.445 | 0.464 | 0.484 | 0.545 |
| Q02 | 0.894 | 0.68 | 0.625 | 0.609 | 0.516 | 0.504 | 0.52 | 0.47 | 0.477 | 0.505 | 0.503 | 0.576 |
| Q03 | 0.856 | 0.776 | 0.661 | 0.584 | 0.538 | 0.481 | 0.469 | 0.495 | 0.482 | 0.541 | 0.49 | 0.556 |



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| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q04 | 0.727 | 0.878 | 0.687 | 0.663 | 0.602 | 0.508 | 0.535 | 0.421 | 0.413 | 0.435 | 0.558 | 0.606 |
| Q05 | 0.733 | 0.884 | 0.73 | 0.689 | 0.615 | 0.549 | 0.555 | 0.496 | 0.424 | 0.534 | 0.487 | 0.574 |
| Q06 | 0.476 | 0.689 | 0.54 | 0.409 | 0.504 | 0.444 | 0.36 | 0.388 | 0.365 | 0.403 | 0.354 | 0.379 |
| Q07 | 0.687 | 0.73 | 0.871 | 0.627 | 0.61 | 0.509 | 0.504 | 0.427 | 0.411 | 0.473 | 0.503 | 0.604 |
| Q08 | 0.592 | 0.702 | 0.87 | 0.608 | 0.535 | 0.51 | 0.53 | 0.428 | 0.387 | 0.48 | 0.511 | 0.543 |
| Q09 | 0.595 | 0.643 | 0.853 | 0.69 | 0.664 | 0.571 | 0.511 | 0.469 | 0.509 | 0.528 | 0.535 | 0.572 |
| Q10 | 0.646 | 0.713 | 0.725 | 0.871 | 0.649 | 0.538 | 0.553 | 0.42 | 0.474 | 0.492 | 0.566 | 0.589 |
| Q11 | 0.603 | 0.621 | 0.63 | 0.889 | 0.673 | 0.587 | 0.591 | 0.529 | 0.49 | 0.539 | 0.602 | 0.549 |
| Q12 | 0.604 | 0.521 | 0.532 | 0.797 | 0.673 | 0.546 | 0.504 | 0.378 | 0.484 | 0.428 | 0.478 | 0.445 |
| Q13 | 0.62 | 0.667 | 0.675 | 0.772 | 0.886 | 0.606 | 0.639 | 0.538 | 0.505 | 0.541 | 0.576 | 0.604 |
| Q14 | 0.436 | 0.458 | 0.416 | 0.509 | 0.716 | 0.597 | 0.407 | 0.464 | 0.431 | 0.44 | 0.447 | 0.416 |
| Q15 | 0.504 | 0.569 | 0.59 | 0.598 | 0.84 | 0.606 | 0.568 | 0.449 | 0.371 | 0.502 | 0.499 | 0.576 |
| Q16 | 0.536 | 0.509 | 0.535 | 0.597 | 0.634 | 0.845 | 0.557 | 0.515 | 0.515 | 0.555 | 0.524 | 0.488 |
| Q17 | 0.499 | 0.537 | 0.467 | 0.519 | 0.637 | 0.819 | 0.564 | 0.396 | 0.386 | 0.456 | 0.504 | 0.515 |
| Q18 | 0.359 | 0.456 | 0.512 | 0.488 | 0.534 | 0.804 | 0.598 | 0.386 | 0.442 | 0.412 | 0.462 | 0.424 |
| Q19 | 0.487 | 0.461 | 0.479 | 0.462 | 0.511 | 0.65 | 0.791 | 0.456 | 0.42 | 0.486 | 0.546 | 0.525 |
| Q20 | 0.424 | 0.494 | 0.496 | 0.574 | 0.575 | 0.536 | 0.808 | 0.567 | 0.45 | 0.452 | 0.552 | 0.457 |
| Q21 | 0.477 | 0.478 | 0.451 | 0.504 | 0.514 | 0.476 | 0.797 | 0.522 | 0.385 | 0.451 | 0.382 | 0.473 |
| Q22 | 0.465 | 0.433 | 0.394 | 0.45 | 0.546 | 0.447 | 0.604 | 0.8 | 0.407 | 0.516 | 0.416 | 0.371 |
| Q23 | 0.475 | 0.467 | 0.451 | 0.411 | 0.472 | 0.46 | 0.52 | 0.855 | 0.495 | 0.516 | 0.468 | 0.444 |
| Q24 | 0.429 | 0.44 | 0.441 | 0.451 | 0.479 | 0.427 | 0.51 | 0.867 | 0.507 | 0.569 | 0.504 | 0.552 |
| Q25 | 0.434 | 0.355 | 0.364 | 0.517 | 0.397 | 0.461 | 0.461 | 0.518 | 0.835 | 0.574 | 0.581 | 0.482 |
| Q26 | 0.478 | 0.42 | 0.402 | 0.467 | 0.476 | 0.442 | 0.418 | 0.424 | 0.898 | 0.588 | 0.477 | 0.498 |
| Q27 | 0.542 | 0.483 | 0.534 | 0.476 | 0.506 | 0.506 | 0.478 | 0.505 | 0.856 | 0.653 | 0.501 | 0.458 |
| Q28 | 0.554 | 0.524 | 0.61 | 0.505 | 0.49 | 0.446 | 0.57 | 0.561 | 0.655 | 0.806 | 0.556 | 0.579 |
| Q29 | 0.478 | 0.433 | 0.377 | 0.447 | 0.547 | 0.497 | 0.438 | 0.513 | 0.5 | 0.844 | 0.536 | 0.514 |
| Q30 | 0.479 | 0.431 | 0.426 | 0.473 | 0.484 | 0.51 | 0.43 | 0.51 | 0.59 | 0.852 | 0.606 | 0.545 |
| Q31 | 0.502 | 0.518 | 0.5 | 0.573 | 0.587 | 0.532 | 0.571 | 0.525 | 0.583 | 0.669 | 0.836 | 0.621 |
| Q32 | 0.524 | 0.512 | 0.464 | 0.522 | 0.501 | 0.501 | 0.498 | 0.421 | 0.434 | 0.523 | 0.839 | 0.639 |
| Q33 | 0.449 | 0.399 | 0.529 | 0.51 | 0.457 | 0.473 | 0.472 | 0.417 | 0.471 | 0.484 | 0.823 | 0.696 |
| Q34 | 0.575 | 0.515 | 0.55 | 0.587 | 0.567 | 0.516 | 0.493 | 0.476 | 0.586 | 0.584 | 0.732 | 0.849 |
| Q35 | 0.566 | 0.549 | 0.536 | 0.467 | 0.602 | 0.498 | 0.531 | 0.436 | 0.389 | 0.528 | 0.623 | 0.848 |
| Q36 | 0.568 | 0.58 | 0.607 | 0.526 | 0.506 | 0.458 | 0.522 | 0.476 | 0.426 | 0.56 | 0.622 | 0.85 |

## 4.2 Structural models

In this section, the structural model is evaluated using the coefficient of determination ($R^2$), effect size ($f^2$), predictive relevance index ($Q^2$), and goodness-of-fit indices.



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### 4.2.1 Calculation of the Coefficient of Determination

The $R^2$ index, or coefficient of determination, indicates the extent to which the model is able to explain the variance of the dependent (endogenous) variable. Chin (1998) proposed the values of 0.19, 0.33, and 0.67 as threshold criteria for weak, moderate, and strong model explanatory power, respectively. The results are presented in Table 7. For example, 68.1% of the variance in variable C1 is explained by the independent variables, which represents a strong level of explanatory power.

**Table 7** Coefficient of determination (R2) index

| Variable | R2 Index |
|---|---|
| C1 | 0.681 |
| C10 | 0.611 |
| C11 | 0.522 |
| C12 | 0.51 |
| C2 | 0.64 |
| C4 | 0.551 |
| C5 | 0.546 |
| C6 | 0.525 |
| C7 | 0.45 |
| C8 | 0.459 |
| C9 | 0.377 |

### 4.2.2 Predictive relevance index

The $Q^2$ index is used to evaluate the predictive power of the model for the endogenous (dependent) variables. A positive $Q^2$ value indicates that the model has adequate predictive capability. $Q^2$ values between 0.02 and 0.15 indicate weak predictive power, values between 0.15 and 0.35 represent moderate predictive power, and values above 0.35 are considered indicative of strong predictive power. If the $Q^2$ value is negative, the model lacks sufficient predictive ability and requires modification. The results are presented in Table 8, which show that the model demonstrates strong and moderate predictive power across all variables.

**Table 8** Predictive correlation index (Q2)

| Variable | Q2 Index | Predictive Result |
|---|---|---|
| C1 | 0.46 | Strong |
| C10 | 0.409 | Strong |
| C11 | 0.344 | Medium |
| C12 | 0.348 | Medium |
| C2 | 0.426 | Strong |
| C3 | - | - |
| C4 | 0.395 | Strong |
| C5 | 0.353 | Strong |
| C6 | 0.342 | Strong |

| | | |
|---|---|---|
| C7 | 0.284 | Medium |
| C8 | 0.32 | Strong |
| C9 | 0.273 | Medium |

### 4.2.3 Effect size calculation

The $f^2$ index indicates which independent variables (exogenous constructs) have a greater contribution to explaining the dependent variable (endogenous construct). Values of $f^2$ between 0.02 and 0.15 indicate weak effects, values between 0.15 and 0.35 represent moderate effects, and values greater than 0.35 are considered strong effects. The results are presented in Table 9, which shows that only the effect of criterion C6 on C10 and C11 is weak, while the remaining effects are moderate to strong.

**Table 9** Effect size index (f2)

| | C1 | C10 | C11 | C12 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | | | | | | | | 0.218 | 0.089 | | 0.079 | 0.162 |
| C10 | | | | | | | | | | | | |
| C11 | | | | | | | | | | | | |
| C12 | | | | | | | | | | | | |
| C2 | 0.492 | | | | | | | | | 0.064 | | |
| C3 | | | | | 1.78 | | 1.227 | | | | | |
| C4 | 0.133 | | | | | | | | | 0.168 | | |
| C5 | | 0.026 | 0.05 | 0.119 | | | | | | | | |
| C6 | | 0.011 | 0.033 | 0.01 | | | | | | | | |
| C7 | | | | | | | | 0.292 | 0.422 | | 0.307 | 0.097 |
| C8 | | 0.091 | 0.024 | 0.024 | | | | | | | | |
| C9 | | 0.27 | 0.102 | 0.054 | | | | | | | | |

### 4.2.4 Model fit indices

In this section, the structural model fit is evaluated using the SRMR, NFI, and the Goodness of Fit (GOF) indices. The SRMR (Standardized Root Mean Square Residual) represents the difference between the observed correlation matrix and the correlation matrix implied by the structural model. In simple terms, SRMR indicates how well the proposed model fits the observed data. The SRMR value ranges between 0 and 1, and values closer to zero indicate a better model fit. Generally, an SRMR value below 0.08 indicates a good model fit, whereas values above 0.10 reflect a poor fit.

The NFI (Normed Fit Index) also improves as it approaches one. An NFI value greater than 0.7 indicates a strong fit, values between 0.3 and 0.7 indicate a moderate fit, and values below 0.3 indicate a weak fit. The results are presented in Table 10. According to the results, the SRMR value is 0.071, which is lower than 0.08 and therefore indicates an acceptable model fit. Moreover, the NFI value is 0.747, which reflects a strong level of model fit.



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**Table 11** SRMR and NFI indices

| Index Name | Value | Fit Status |
|---|---|---|
| SRMR (Standardized Root Mean Square Residual) | 0.069 | Strong Fit |
| NFI (Normed Fit Index) | 0.637 | Medium Fit |

The final goodness-of-fit measure is the GOF (Goodness of Fit) index, which is used to assess the overall fit of the model. Values closer to one indicate an acceptable model quality. This index evaluates the model's overall predictive capability and shows whether the tested model has been successful in predicting endogenous latent variables. To assess the overall model fit, the GOF criterion is employed, where values of 0.10, 0.25, and 0.36 are considered weak, moderate, and strong, respectively, for evaluating the validity of PLS models. The results presented in Table 11 show that the GOF value is 0.610, indicating a strong overall model fit.

**Table 12** Goodness of fit (GOF) index data

| Variable | Coefficient of Determination (R2) | Communality Values (AVE) |
|---|---|---|
| C1 | 0.681 | 0.693 |
| C10 | 0.611 | 0.696 |
| C11 | 0.522 | 0.694 |
| C12 | 0.51 | 0.721 |
| C2 | 0.64 | 0.676 |
| C3 | - | 0.748 |
| C4 | 0.551 | 0.728 |
| C5 | 0.546 | 0.667 |
| C6 | 0.525 | 0.677 |
| C7 | 0.45 | 0.638 |
| C8 | 0.459 | 0.707 |
| C9 | 0.377 | 0.745 |
| $GOF = \sqrt{\overline{communalities\ (AVE)} \times \overline{R^2}} = 0.610$ | | |

## 4.3 Discussion

The results of this study reveal that economic, technical, and organizational factors respectively play key roles in shaping the resilience of the sesame supply chain in Yazd Province. This ranking indicates that economic conditions such as price stability, access to financial facilities, and cost management form the primary layer of vulnerability and resilience in this agricultural system. In other words, economic resilience acts as the first shield against external shocks, whereas technical and organizational capabilities serve as enabling and sustaining mechanisms that enhance long-term adaptability. The strong and significant path coefficients in the structural equation model confirm that improvements in economic performance exert the most direct effect on resilience, while investments in technological innovation and inter-organizational coordination amplify these effects over time. The model's good fit indices demonstrate that the proposed causal structure accurately reflects the real dynamics among resilience determinants, providing a reliable framework for



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prioritizing managerial interventions. From a managerial standpoint, this means that policymakers should first stabilize the economic foundations of the supply chain through guaranteed purchase pricing, financial support, and cost-effective logistics then proceed to strengthen technical infrastructure such as modern irrigation and information systems, and finally consolidate organizational collaboration mechanisms among producers, processors, and distributors. This sequential approach ensures both short-term responsiveness and long-term sustainability. The integration of fuzzy Delphi and SEM in the research framework also contributes theoretically by offering a robust, replicable model for evaluating supply chain resilience in agricultural contexts. Overall, the results not only provide numerical evidence but also present a coherent analytical narrative linking quantitative outcomes to practical strategies and policy directions, thereby enriching both the academic and applied dimensions of the study.

## 5 Conclusion

The sesame industry, as one of the important and strategic industries in Yazd Province, plays a significant role in ensuring farmers' livelihoods and promoting regional economic development. Given the specific characteristics of this product and the need to ensure appropriate quality and quantity throughout the supply chain, supply chain resilience is recognized as a key factor in the success and sustainability of this industry. Supply chain resilience refers to the ability to cope with challenges and crises, including climate change, market fluctuations, and difficulties in sourcing raw materials. In recent years, sesame-related industries have faced numerous challenges that may lead to reduced performance and product quality. Therefore, designing resilience scenarios to identify and manage these challenges is essential. Approaches such as structural equation modeling can assist in analyzing the complex relationships among factors affecting supply chain resilience and in simulating different scenarios. Structural equation modeling, as a powerful analytical tool, enables the examination of causal relationships among variables. This study aims to design effective scenarios to enhance the resilience of the sesame supply chain in Yazd Province by examining and analyzing these tools and methods. Accordingly, this research focuses on analyzing and designing supply chain resilience scenarios for the sesame industry in Yazd Province and, by employing structural equation modeling approaches, identifies and analyzes the factors influencing the resilience of this supply chain. Given the importance of the sesame industry in the local economy and the numerous challenges it faces, designing effective scenarios can contribute to improving the performance and resilience of this supply chain. Considering the strategic importance of sesame and its role in the local economy, the need for a resilient and flexible supply chain capable of withstanding various challenges including climate change, market volatility, and logistical problems is clearly evident. To this end, the present study first identified and classified the factors affecting supply chain resilience. Using a meta-synthesis approach, 24 criteria were identified and categorized into three groups: technical, economic, and organizational. Through the application of the fuzzy Delphi method, 12 criteria were eliminated and 12 final criteria were retained. Subsequently, the relationships among these factors were analyzed and examined using structural equation modeling. Various tests, including the coefficient of determination, predictive relevance, and effect size, were employed, and strong relationships were identified across all tests. The findings of this study can assist decision-makers and managers in the sesame industry by enabling a better understanding of challenges and opportunities and supporting the development of effective



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strategies to improve supply chain resilience and performance. Furthermore, this research can serve as a model for other similar industries in Yazd Province and other regions of the country. Finally, by emphasizing the importance of collaboration among various stakeholders, infrastructure development, and the use of modern technologies, this study seeks to provide practical and applicable solutions to enhance the resilience of the sesame supply chain in Yazd Province. Attractive directions for future research include the application of system dynamics to examine the long-term effects of factors influencing resilience, as well as investigating the social and economic impacts of the sesame supply chain on local communities and proposing solutions to increase social benefits.

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