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Using the fuzzy TOPSIS method to identify and prioritize factors affecting the implementation of the circular economy of bread

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Abstract

Food waste in supply chains presents significant challenges, necessitating efforts to recapture lost value. Circular economy approaches offer solutions to address these issues. This study examines the circular economy of bread in Iran, aiming to identify and prioritize factors for its implementation using the fuzzy TOPSIS method. Through interviews with 20-grain industry experts in Isfahan Province, we identified 38 basic and five formative factors. Fuzzy TOPSIS was then employed to rank these factors based on expert preferences. Key findings reveal that reducing bread waste depends on critical factors such as efficient utilization of bread waste, consumer behavior patterns related to bread consumption, production practices within the bread industry, flour production and storage processes, and government policy effectiveness. The most significant impact came from the diversity and dispersion of small collection centers for stale bread in peri-urban areas. Additionally, fluctuating demand for bread, leading to surpluses and rapid staleness, and the use of waste in animal feed production contribute significantly to waste. While all identified factors are critical, their importance is nearly equal, emphasizing the need for a comprehensive approach to effectively implement a circular economy for bread in Iran.

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Introduction

The global population is expected to reach 9 billion by 2030, increasing food security demand (Al Hosni et al., 2020). Consequently, food waste has become a critical concern at the macro level. Bread, a staple food source rich in energy and protein, experiences significant waste throughout the production, distribution, and consumption chain (Isbasoiu et al., 2021, Esfahani, 2022). This waste has numerous negative consequences, including the inefficient use of raw materials, energy, and labor (Munesue et al., 2015). In recent years, the circular economy has emerged as a promising solution for waste reduction, integrating social benefits and environmental protection (Kiani and Andalib Ardakani, 2022). The circular economy, grounded in concepts such as sustainable development, green economy, life cycle analysis, ecosystem services, shared value, and extended producer responsibility, advocates a fundamental shift from linear to closed-loop systems. These closed-loop systems reintegrate waste and recycled materials as valuable resources (Bai et al., 2021). Its core principle is the responsible and mindful utilization of all human, natural, and economic resources (Urom et al., 2022).

The European Commission's 2015 Circular Economy Action Plan emphasizes maximizing the value of products, materials, and resources throughout the economic cycle, minimizing waste generation (Kiani, 2023). By fostering sustainable product design, the circular economy presents opportunities for optimizing production processes and preserving product value for extended periods (Adebanjo et al., 2021). Furthermore, the concept is closely intertwined with circular supply chain management, establishing a continuous loop of reuse, recycling, and regeneration (Bianchini et al., 2019). Adopting a circular approach to material and product flows presents a significant opportunity for organizations to mitigate the environmental impact of inefficiencies within their supply chains. The circular economy presents a compelling solution to address environmental challenges and resource depletion (Vares et al., 2022).

Iran faces a growing challenge, with per capita waste generation exceeding the global average (Ghorbanpur et al., 2022). With a population of approximately 80 million, waste production has increased from 18 million to 20 million tons, and if this trend persists, achieving the goals outlined in upstream policy documents will become increasingly tricky (Ghorbanpur et al., 2022, Salem and Mojaverian, 2017). Therefore, identifying internal and external challenges is crucial for organizations to assess opportunities and potential risks associated with implementing a circular economy (Garcés-Ayerbe et al., 2019, Ghaziani et al., 2023).

Given the issues above, it is imperative to identify and prioritize factors impacting the implementation of a circular economy for bread. Previous research has not comprehensively addressed the factors influencing bread waste recycling and reuse. This study, as illustrated in Figure 1, focuses explicitly on bread waste, with the primary objective of identifying and prioritizing critical factors that influence the implementation of a circular economy for bread. Recognizing the challenges within the food system, particularly bread waste, serves as a crucial foundation for developing practical and hopeful solutions for waste reuse and recycling. This research, informed by this practical perspective, aims to answer the question, "What factors most significantly impact the implementation of a circular bread economy?"

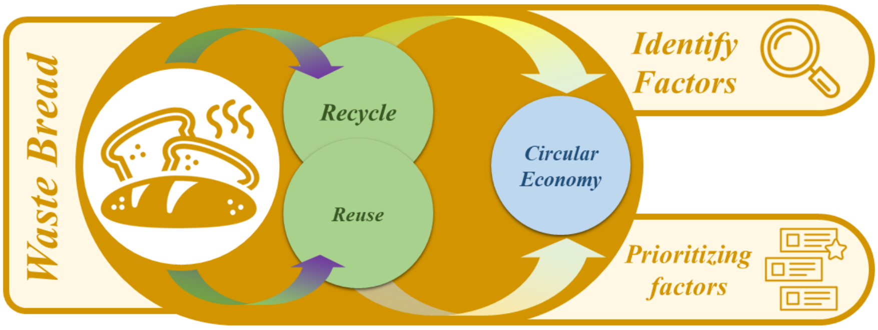

Figure 1. The structure of the main focus in the current research

This research explores the intersection of three key areas within the existing literature: circular economy principles, bread waste management, and its potential for recycling and reuse. In contrast to prior studies that have examined these areas independently, this research employs a holistic approach. By integrating these key elements, we aim to identify the factors influencing the successful implementation of a circular economy model for bread waste management. We will glean the factors from expert interviews and subject them to quantitative and qualitative analysis for a comprehensive understanding. Table 1 provides a critical overview of relevant prior research. Notably, a gap exists regarding exploring bread waste recycling and reuse within the framework of circular economy concepts. In response to this knowledge gap, this study seeks to identify the critical factors influencing the successful adoption of a circular economy model for bread waste management. The research will specifically focus on the potential to recycle and reuse bread waste streams.

Table 1. Comparison of the points of focus in the subject literature

	Circular economy concepts	Waste bread	Recycle and reuse
(Kiani, 2023)	✓		
(Kiani and Andalib Ardakani, 2022)	✓		
(Hosseinpoor and Ghorbanpour, 2023)	✓		
(Singh et al., 2023)	✓		
(Mirzadeh and Rezaeian, 2021)		✓	✓
(Gómez and Martinez, 2023)		✓	✓
(Ghaziani et al., 2023)		✓	
Current Study	✓	✓	✓

Numerous studies have focused on the circular economy and bread waste. This section provides an overview of some critical research in these areas. Within the field of circular economy research, (Kiani, 2023) provides a literature review that clarifies the key differences between circular and linear economic models. This review emphasizes the significance of the circular economy within the broader economic landscape. The research introduces various patterns and strategies, such as design and waste reuse, industrial symbiosis, recycling, refurbishment, and digital technologies, which enhance the understanding of upstream and downstream industry actions and their synergy with other strategies. In the context of implementing a circular economy, (Kiani and Andalib Ardakani, 2022) propose a new model for implementing a circular economy that identifies the challenges polluting industries face. Their findings indicate that economic challenges are the most influential, while market and design challenges also play significant roles. The systematic evaluation of each challenge's effectiveness and impact provides a strategic roadmap for managers and experts seeking to implement circular economy principles in polluting industries.

Furthermore, (Hosseinpoor and Ghorbanpour, 2023) examine the components of the circular economy, clean production, and Industry 4.0 in the digitization era. In a fuzzy environment, they use the gradual weighting evaluation ratio analysis (Savara method) to analyze data and identify the main factors affecting the implementation of the circular economy. They gathered expert opinions through questionnaires, pinpointing the critical factors. Additionally, (Singh et al., 2023) explore the key factors influencing businesses to adopt circular practices. Their study highlights senior management involvement, the market for recycled products, and promoting circular economy-based research and development as top priorities for stakeholders. This study investigates explicitly the recycling and reuse of bread waste as a strategy for implementing circular economy principles.

Bread waste has substantial potential for recycling and reuse, attracting significant research interest. For instance, (Mirzadeh and Rezaeian, 2021) investigated using environmental bacteria and bread waste to produce bio-butanol, demonstrating that bread waste can optimally produce bio-butanol. Similarly, (Gómez and Martinez, 2023) explore the redistribution of surplus bread within the food supply chain. Their research assesses the safety risks, regulations, and challenges associated with using excess bread as food. They emphasize the potential of surplus bread flour as an edible component and its suitability for biotechnological applications in food production. The study reveals that bread flour, with its cold thickening and water-holding capacities, integrates successfully into semi-solid foods or serves as a substrate for biotechnological applications such as sourdough production.

Given the importance of wheat and bread as primary food sources, reviewing and analyzing these products can further the research goals of the circular economy about bread. Ghaziani et al. (2023) investigate the value flow, waste, and critical data gaps throughout the life cycle of wheat and bread. Their cradle-to-grave analysis identifies farms, food services, and households as primary waste producers. The research provides crucial insights into wheat loss in fields and household bread waste.

Drawing upon the insights from these prior studies, our research endeavors to identify and prioritize the factors that influence the successful implementation of a circular economy model for bread waste management. This study introduces an innovative approach by integrating circular economy principles with Iran's unique challenges of bread waste management. Unlike previous studies, which have treated these areas in isolation, we employ the Fuzzy TOPSIS method to offer a comprehensive framework for prioritizing the factors critical to implementing a circular bread economy. This research fills a significant gap in the literature and provides practical insights tailored to the Iranian context. By synthesizing concepts from existing literature on the circular economy and bread waste, we strive to develop a comprehensive understanding and strategic framework to advance the circular economy within this sector.

Materials and Methods

Based on the discussed concepts, the fundamental features of the circular economy can be summarized as follows:

- ***Elimination of Waste:*** The meticulous design of a product's biological and industrial components, ensuring compatibility within their lifecycles, can eliminate waste. Non-toxic biological materials are easily converted into fertilizers. Conversely, industrial materials, such as polymers, alloys, and other synthetic compounds, are designed to be reused with minimal energy consumption while maintaining the highest quality (Ghorbanpur et al., 2022).
- ***Flexibility:*** This characteristic highlights the importance of diversification, adaptability, and the capacity for change. Systems with diverse and extensive connections are more flexible and resilient to external shocks than those optimized solely for efficiency (Graziano et al., 2019, Karaoulanis, 2024).
- ***Intra-System Thinking:*** The interactions between components within a system and the system's mutual influence on its components are critical. Such systems are typically non-linear, highly interconnected, and characterized by

feedback loops (Garcia Rodriguez et al., 2024).

- ***Cascade Thinking:*** Maximizing added value through successive uses is crucial in natural materials and goods. Biological processes, like controlled fermentation or natural decomposition by microorganisms, release energy and nutrients from carbohydrates, fats, and proteins (Rios and Grau, 2019).

Leveraging established circular economy principles, a critical analysis of operational approaches to implementing these practices within the bread sector is warranted. Drawing upon the theoretical foundations of the circular economy, this research endeavors to minimize waste generation and promote reuse practices within the bread sector. We aim to develop a practical framework that systematically identifies and analyzes the factors influencing a circular economy model for bread.

Through their experience within the operational environment, interviewees possess a deeper understanding of the practical limitations and challenges hindering bread waste reuse initiatives compared to other stakeholders in the bread supply chain. We applied reliability and verifiability criteria to ensure the adequacy and quality of the research process and data.

- **Reliability:** This criterion indicates the extent to which the research results accurately represent the data.
- **Verifiability:** This criterion assesses the extent to which the interpretations reflect the interviewees' perspectives rather than the researcher's biases.

Additionally, analytical data were collected using a questionnaire designed for the fuzzy TOPSIS method. We piloted the questionnaire beforehand with the interviewees to ensure its validity. Based on their feedback, we finalized the instrument. We then employed the fuzzy TOPSIS method to prioritize the factors influencing the successful implementation of a circular economy model for bread waste management.

Fuzzy TOPSIS is a multi-criteria decision-making method that selects the best option based on its fuzzy distance from positive and negative ideals (Rahiminezhad Galankashi et al., 2024) A decision matrix will be developed to facilitate informed decision-making. This matrix will assign scores to each option based on pre-defined criteria. The fuzzy TOPSIS method is not applicable if the decision matrix values originate from actual figures and available statistics, as definitive values eliminate ambiguity. However, expert opinions often score each option against each criterion, and fuzzy calculations produce better results. The data collection process for fuzzy TOPSIS necessitates using an appropriate linguistic scale (Dhull and Narwal, 2018). This research uses a five-degree range for qualitative evaluation in the fuzzy TOPSIS technique, as shown in Table 2.

Table 2. Fuzzy numbers considered in the research

Fuzzy numbers	Words
(1,1,3)	Very little
(1,3,5)	Low
(3,5,7)	Medium
(5,7,9)	Much
(7,9,11)	Very much

This section outlines the fuzzy TOPSIS method, a decision-making aid employed by (Nadaban et al., 2016) to rank and prioritize factors.

Step 1: Creating a Fuzzy Decision Matrix

Assuming we have m options, n criteria, and k decision-makers (evaluators), the fuzzy multi-criteria group decision-making problem can be expressed as follows: Let represent the options that must be selected or prioritized and the evaluation criteria. Based on this, the evaluator evaluates the option for the criterion. The mean value method is employed to integrate the performance scores from all evaluators. This approach averages the evaluations to create a consolidated fuzzy decision matrix.

$$\widetilde{D} = \begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1j} & \cdots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{x}_{i1} & \cdots & \tilde{x}_{ij} & \cdots & \tilde{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mj} & \cdots & \tilde{x}_{mn} \end{bmatrix} \quad (1)$$

$$i = 1,2,\dots,m; j = 1,2,\dots,n$$
$$\tilde{x}_{ij} = \frac{1}{k}(\tilde{x}_{ij}{}^{1} + \tilde{x}_{ij}{}^{2} + \dots + \tilde{x}_{ij}{}^{k})$$

Step 2: Determination of the Criteria's Weight Matrix

At this stage, the importance coefficients of the decision-making criteria are determined, which can be defined using triangular fuzzy numbers, as shown in equation (2). Each component of W (the weight of each criterion) is represented as $\widetilde{W}_J = (\widetilde{W}_{j1}, \widetilde{W}_{j2}, \widetilde{W}_{j3})$. To calculate the fuzzy weights, we use relationships (3) for fuzzy ranking. These relationships allow us to rank the fuzzy numbers, enabling us to compute the fuzzy weights based on the decision-makers evaluations of each criterion's significance. By leveraging these relationships, the fuzzy numbers can be ranked. This ranking, in turn, allows for the calculation of fuzzy weights, which reflect the decision-maker's assessment of the relative importance of each criterion. The decision-makers express their opinions using verbal values, converted into corresponding triangular fuzzy numbers to form the criteria's weight matrix.

$$\widetilde{W} = [\widetilde{W}_1, \widetilde{W}_2, \dots, \widetilde{W}_j, \dots, \widetilde{W}_n] \quad (2)$$

$$\widetilde{w}_{j1} = \min_k\{w_{jk1}\}, \widetilde{w}_{j2} = \frac{\sum_{k=1}^{K} w_{jk2}}{K}, \widetilde{w}_{j3} = \max_k\{w_{jk3}\} \quad (3)$$

Step 3: Normalizing the Fuzzy Decision Matrix

Equations (4) through (6) will normalize the fuzzy decision matrix.

$$\tilde{R} = [\tilde{r}_{ij}]_{m\times n}, \quad i = 1,2,\dots,m; j = 1,2,\dots,n \quad (4)$$

$$\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}) \quad (5)$$

$$\tilde{r}_{ij} = \begin{cases} if\ positive: \left(\frac{a_{ij}}{c_j{}^{+}}, \frac{b_{ij}}{c_j{}^{+}}, \frac{c_{ij}}{c_j{}^{+}}\right); & c_j{}^{+} = \max_i c_{ij} \\ if\ negative: \left(\frac{a_j{}^{-}}{c_{ij}}, \frac{a_j{}^{-}}{b_{ij}}, \frac{a_j{}^{-}}{a_{ij}}\right); & c_j{}^{-} = \min_i a_{ij} \end{cases} \quad (6)$$

Step 4: Creating the Weighted Normalized Fuzzy Decision Matrix

Calculating the weighted normalized fuzzy decision matrix involves multiplying the importance weights of the criteria by the normalized fuzzy decision matrix. The weighted normalized fuzzy decision matrix V is defined by equation (7), where $\widetilde{w}_j$ represents the weight of the criterion j. Essentially, this step involves multiplying the matrices obtained from Steps 2 and 3.

$$\tilde{V} = [\tilde{v}_{ij}]_{m\times n}, \quad i = 1,2,\dots,m \; ; \tilde{v}_{ij} = \tilde{r}_{ij} \otimes \widetilde{w}_j \quad (7)$$

Step 5: Determination of Ideal Solution and Negative Ideal Solution

The definition of both ideal and anti-ideal scenarios is crucial for identifying the optimal solution utilizing the established criteria. The ideal solution maximizes the benefit criteria and minimizes the cost criteria, representing the best values for all requirements. Conversely, the anti-ideal solution combines the worst values of the available criteria. Thus, the optimal option is closest to the ideal solution and farthest from the anti-ideal solution. The fuzzy ideal solution $\tilde{v}_j{}^{*}$ and the fuzzy anti-ideal solution j are defined by equation (8). Here, $\tilde{v}_j{}^{*}$ represents the best value of the criterion j among all alternatives, and $\tilde{v}_j{}^{*}$ represents the worst value of criterion j among all alternatives in the weighted fuzzy decision matrix. These values are calculated using equation (9).

$$A^{*} = \{\tilde{v}_1{}^{*}, \tilde{v}_2{}^{*}, \dots, \tilde{v}_n{}^{*}\}, A^{-} = \{\tilde{v}_1{}^{-}, \tilde{v}_2{}^{-}, \dots, \tilde{v}_n{}^{-} \quad (8)$$

$$\tilde{v}_j{}^{*} = \max\{\tilde{v}_{ij}\} \quad i = 1,2,\dots,m; \; j = 1,2,\dots,n$$
$$\tilde{v}_j{}^{-} = \min\{\tilde{v}_{ij}\} \quad i = 1,2,\dots,m; \; j = 1,2,\dots,n \quad (9)$$

Options in A^{*} and A^{-} represent better and worse options, respectively. After constructing the balanced fuzzy normal matrix, the TOPSIS ranking mechanism is employed to identify the positive and negative ideal solutions. This process involves identifying each criterion's most favorable and least favorable values. This is achieved by conducting a comparative analysis of the entries within the balanced fuzzy normal matrix. The positive ideal value corresponds to the maximum value within each column. Conversely, the negative ideal solution represents the least favorable scenario. It is identified by selecting the minimum value within each weighted normalized fuzzy decision matrix column.

Step 6: Calculating the distance size

In fuzzy TOPSIS, the distance of each alternative is calculated relative to both the ideal (positive) solution and the fuzzy negative ideal solution. Equation (10) exemplifies this fuzzy distance calculation.

$$d(\tilde{v}_{ij}, \tilde{v}_j^{+}) = \sqrt{\frac{1}{3}[(a-1)^2 + (b-1)^2 + (c-1)^2]}\,, d(\tilde{v}_{ij}, \sqrt{\frac{1}{3}[(a-0)^2 + (b-0)^2 + (c-0)^2]} \quad (10)$$

Step 7: Calculating the Proximity Coefficient and Prioritizing Options

Determining the proximity coefficient enables the calculation of the ranking for all options, aiding decision-makers in selecting the optimal choice. Equation (11) calculates the proximity coefficient for each option.

$$C_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \quad i = 1,2,\dots,m \quad (11)$$

Step 8: Ranking the Options

Finally, the alternatives can be ranked according to their relative closeness to the ideal solution, with the closest alternative receiving the highest rank.

Results and discussion

Building upon the qualitative data analysis procedures outlined in the preceding sections, Table 3 presents the key findings from this research stage. We identified 38 fundamental themes across five categories as influential factors affecting the implementation of the circular bread economy by examining and analyzing the identified indicators and components. Following their extraction, we further categorized these basic themes into constructive ones. Next, we used the fuzzy TOPSIS method to rank the influential factors, considering four rating criteria based on the characteristics of the circular economy, as discussed extensively in the theoretical foundation's section on the circular economy.

Table 3. Factors affecting the implementation of circular economy

Constructive theme	Basic theme (effective factors)	Abundance	Symbol
Production and storage of flour	The type of flour used	7	ALT1
	Non-uniformity in flour quality and non-standard delivery of flour to bakers	5	ALT2
	Wheat harvest time	7	ALT3
	The number of silos	10	ALT4
	Unsuitability of wheat for consumption	8	ALT5
Bread production	Quality of manufactured bread	10	ALT6
	Low (relative) price of bread	10	ALT7
	Lack of skills of bakery workers	8	ALT8
	Failure to use the correct technology to produce dough and bake bread	5	ALT9
	Lack of supervision and serious control over bread production	10	ALT10
	Non-uniform baking of bread	5	ALT11
	Using inappropriate and non-standard ovens for bread production	5	ALT12
	How to carry bread	4	ALT13
	Type of bread	5	ALT14
	Methods of baking bread and preparing dough	3	ALT15
Consumers	Increase in demand during the hours of the day due to the rapid staleness of bread	8	ALT16
	Not informing consumers about the correct way to store bread	6	ALT17
	Failure to comply with the necessary conditions to prevent waste in restaurants, self-services, and homes during the distribution and consumption of bread at the table	6	ALT18
	Monthly income	6	ALT19
	The number of bread meals per week	8	ALT20
	Waiting time in the bakery	4	ALT21
	Number of household members	4	ALT22
	Age of household members	5	ALT23
	Education of family members	6	ALT24

Constructive theme	Basic theme (effective factors)	Abundance	Symbol
	Frequency of visits to the bakery	4	ALT25
Use of bread waste	Preparation of feed for monogastric animals, including poultry, aquatic animals, and pets	9	ALT26
	The impossibility of continuous access to the mass of these wastes	3	ALT27
	The number and smallness of dry bread collection centers and their dispersion in the outskirts of cities	3	ALT28
	Instability and non-uniformity of the composition of bread waste for the production of chemical compounds	10	ALT29
	The contamination of bread waste with mold and hazardous levels of fungal toxins	7	ALT30
	Production of by-products from waste	3	ALT31
	Production of bread powder containing binders with fungal toxins from waste	6	ALT32
	Production of pastes with different compositions for rearing insect larvae as a source of animal protein for animal feed	3	ALT33
	Production of various types of feed for pets in combination with materials such as slaughterhouse waste	9	ALT34
	Choosing the waste collection method according to the type of bread	3	ALT35
Government performance	The government's inability to control mid-term waste or effectively reduce bread and bakery waste	3	ALT36
	Investing in the creation of appropriate workshops and industries for the centralized processing of these wastes in each province	6	ALT37
	Implementation of new rules for baking bread	6	ALT38

Table 4 presents the results of the fuzzy decision matrix analysis. This matrix considers the four key characteristics of the circular economy and incorporates expert preferences. It provides a detailed breakdown of fuzzy preference scores for each option, enabling a nuanced examination of individual expert assessments.

Table 4. Fuzzy decision matrix

Factor	Cascade Thinking			Intra-System Thinking			Flexibility			Removal of waste		
ALT1	1	1	3	3	5	7	1	3	5	1	3	5
ALT2	1	3	5	5	7	9	3	5	7	3	5	7
ALT3	3	5	7	7	9	11	1	1	3	5	7	9
ALT4	5	7	9	1	3	5	1	3	5	7	9	11
ALT5	7	9	11	3	5	7	3	5	7	5	7	9
ALT6	1	1	3	5	7	9	5	7	9	7	9	11
ALT7	1	3	5	1	1	3	7	9	11	1	3	5
ALT8	3	5	7	1	3	5	1	1	3	3	5	7
ALT9	1	3	5	3	5	7	1	3	5	5	7	9
ALT10	3	5	7	1	1	3	3	5	7	7	9	11
ALT11	5	7	9	1	3	5	1	1	3	7	9	11
ALT12	1	3	5	1	1	3	1	3	5	1	3	5
ALT13	1	1	3	1	3	5	1	1	3	3	5	7
ALT14	1	1	3	3	5	7	1	3	5	1	1	3
ALT15	1	3	5	5	7	9	3	5	7	1	3	5
ALT16	3	5	7	7	9	11	5	7	9	3	5	7
ALT17	11	6	11	3	4	1	9	11	11	2	3	6
ALT18	3	7	4	9	5	1	9	7	4	9	9	5
ALT19	10	6	2	9	3	10	1	9	6	9	8	11
ALT20	10	2	11	9	6	4	4	4	10	3	2	8
ALT21	6	11	9	7	1	11	11	10	11	11	2	2
ALT22	6	10	1	2	2	5	9	3	7	7	7	10
ALT23	8	11	1	1	3	8	4	10	3	1	1	10
ALT24	5	8	5	8	4	2	8	10	1	2	8	8
ALT25	4	7	8	9	10	6	7	1	3	3	7	2

Factor	Cascade Thinking			Intra-System Thinking			Flexibility			Removal of waste		
ALT26	11	5	2	6	3	2	11	9	4	9	1	4
ALT27	11	3	5	1	2	5	3	10	8	4	8	1
ALT28	6	8	3	11	10	7	6	5	5	5	9	9
ALT29	1	11	6	8	5	9	2	6	6	10	8	5
ALT30	2	6	10	2	9	7	1	4	3	10	10	1
ALT31	11	8	4	2	11	8	2	4	4	5	4	9
ALT32	6	2	2	8	6	1	11	2	10	1	1	6
ALT33	3	4	5	6	1	7	4	9	1	3	8	7
ALT34	7	6	4	7	6	3	3	3	4	6	8	1
ALT35	4	5	11	4	1	5	11	7	11	4	1	11
ALT36	1	8	3	10	11	2	8	8	1	2	4	3
ALT37	6	1	10	9	2	1	11	4	6	7	10	7
ALT38	8	10	3	8	7	8	6	1	8	10	5	11

Additionally, Table 5 displays the overall weights of the criteria (i.e., W) individually for each core criterion of the circular economy. These values enable a fuzzy observation of the weights, thereby facilitating the quantitative determination of the significance of qualitative criteria.

Table 5. The results of the overall weights of the criteria (W)

Criterion	Lower limit	Average Limit	Upper Limit
Removal of waste	5	7	9
Flexibility	3	5	7
Intra-System Thinking	5	7	9
Cascade Thinking	7	9	11

Table 6 presents the calculated values for the positive ideal (D^+), negative ideal (D^-), distance from the positive ideal, distance from the negative ideal, the value of C based on the relationships outlined in the sixth section, and the ranking of each factor. As depicted in Table 6, the constructive themes of waste utilization and consumer engagement have emerged as the most influential factors for implementing the circular economy of bread. Following closely in subsequent ranks are bread production, flour production and storage, and bread yield, respectively, identified as pivotal factors examined in this study.

Table 6. Results of ranking calculations

Factor	D^+	D^-	Distance from the positive ideal	Distance from the negative ideal	C	Rank in the theme builder	Overall rating
ALT1	5.000	0.455	3.875	5.302	0.083	1	9
ALT2	7.000	0.455	6.097	7.736	0.061	3	17
ALT3	9.000	0.455	7.467	9.032	0.043	4	27
ALT4	11.000	0.273	8.614	10.115	0.024	5	38
ALT5	9.000	0.818	8.622	10.301	0.083	۲	10
ALT6	11.000	0.455	8.874	10.420	0.041	5	29
ALT7	9.000	0.273	6.369	7.743	0.029	8	34
ALT8	7.000	0.273	5.215	6.655	0.038	6	32
ALT9	9.000	0.455	6.482	7.974	0.045	4	26
ALT10	11.000	0.273	8.338	9.808	0.025	10	37
ALT11	11.000	0.273	8.455	9.883	0.026	9	36
ALT12	5.000	0.273	3.708	5.051	0.052	3	23
ALT13	7.000	0.273	4.355	5.619	0.037	7	33
ALT14	4.455	0.455	3.213	4.582	0.093	1	7
ALT15	5.727	0.455	5.273	6.870	0.074	2	13
ALT16	7.364	1.364	7.617	9.359	0.156	1	2
ALT17	9.000	0.636	8.670	10.252	0.066	6	16
ALT18	7.364	0.636	6.496	8.233	0.080	5	12
ALT19	11.000	0.455	8.999	10.647	0.042	9	28
ALT20	9.000	1.273	7.937	9.492	0.124	2	5

Factor	D^+	D^-	Distance from the positive ideal	Distance from the negative ideal	C	Rank in the theme builder	Overall rating
ALT21	9.000	0.455	9.359	11.041	0.048	8	25
ALT22	10.000	0.545	7.848	9.411	0.051	7	24
ALT23	10.000	0.273	7.596	8.975	0.027	10	35
ALT24	8.000	0.818	6.967	8.570	0.093	3	6
ALT25	6.545	0.636	5.691	7.399	0.089	4	8
ALT26	5.727	0.818	5.677	7.347	0.125	3	4
ALT27	6.545	0.273	6.441	7.998	0.040	9	30
ALT28	9.000	2.455	7.679	9.461	0.214	1	1
ALT29	7.000	0.455	7.653	9.379	0.060	5	18
ALT30	8.182	0.455	7.447	8.951	0.053	8	22
ALT31	9.000	0.545	7.126	8.807	0.057	7	20
ALT32	8.182	0.636	5.796	7.187	0.070	4	15
ALT33	7.000	0.455	6.201	7.747	0.059	6	19
ALT34	6.545	1.000	4.737	6.449	0.133	2	3
ALT35	11.000	0.455	9.467	10.954	0.039	10	31
ALT36	5.091	0.455	4.870	6.515	0.082	1	11
ALT37	8.182	0.636	7.961	9.546	0.072	2	14
ALT38	11.000	0.636	8.811	10.480	0.055	3	21

The resulting bread's quality has a significant impact on its desirability. Regarding the constructive theme of "bread production," the type of bread emerges as a crucial factor, as expected. This aspect contributes to Iran's high bread waste production rate compared to developed countries. Bread's appearance and technical characteristics, such as thickness and surface texture, influence its perishability. These factors can vary significantly across different bread types. Conversely, concerning the constructive theme of "government performance," the government's inability to effectively control or reduce bread and bakery waste over the medium term has been identified as a primary characteristic. Food industry experts identify specific dimensions of government policy as posing challenges to implementing circular food economy principles. In the overall ranking of indicators, the factor of the number and distribution of dry bread collection centers, identified within the constructive theme of "utilization of bread waste," holds the top position. This variation in perishability exacerbates the challenges of reusing bread scraps. It highlights the critical need for infrastructure to support both collection and recycling processes. Furthermore, within the constructive theme of "consumers," increased demand during certain hours due to bread's rapid staleness ranks second among all identified indicators. This underscores consumers' behavior-oriented demand patterns.

Conclusions and suggestions

This study employed the fuzzy TOPSIS method to identify and prioritize factors that influence implementing a circular bread economy. The research findings underscored several key factors, with constructive themes such as bread waste utilization, consumer behavior, bread and flour production and storage, and governmental performance emerging as pivotal influencers in the circular economy of bread. Among the identified factors, we deemed the number, size, and distribution of dry bread collection centers on the outskirts of cities to be the most critical. Prominently among the identified factors were the significant fluctuations in bread demand throughout the day and the use of bread waste in producing various animal feeds. The study identified the need to carefully consider flour production and storage practices to ensure consistent and desired flour quality. The study identified flour production and storage practices as crucial factors requiring careful consideration to ensure consistent flour quality.

The study identified bread type, baking techniques, and bread quality as crucial determinants in bread production. On the other hand, the study identified consumer behavior patterns, which include improper bread storage and increased demand during specific hours, as the primary contributors to waste generation. The study also identified inadequate waste control policies as a significant impediment to improved governmental performance in this area.

Given the relative proximity of the prioritized factors, it is clear that each plays a crucial role in the successful implementation of a circular bread economy. These findings underscore the need for policymakers and stakeholders in the bread sector to comprehensively assess all the dimensions and factors identified in this study. Considering the current uncertainty surrounding the circular economy of bread among Iran's supply chain stakeholders, there is a strong need for data-driven research to support informed, macro-level decision-making based on up-to-date information.

Future research should also explore alternative multi-criteria decision-making (MCDM) methods, such as the Analytical Network Process (ANP) and VIKOR, to enhance the ranking of factors and enable comparison with the findings of this study. Moreover, simulation models could provide valuable insights into the interrelationships among factors and support the analysis of various implementation scenarios for the circular bread economy. In conclusion, incorporating complementary quantitative approaches can deepen our understanding of the system dynamics within the circular economy framework.

Data Availability
The data supporting this study are available from the corresponding author upon reasonable request.

Conflict of Interest
The authors declare no competing interests.

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