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Effects of human and infrastructural factors on the quality of bread: A case study in Dezful County, Iran Seid Reza Falsafi*, Ramin Gooruee

Agricultural Engineering Research Department, Food Science and Technology Division, Safiabad Agricultural and Natural Resources Research and Education Center, (AREEO), Dezful, Iran

ARTICLE INFO	ABSTRACT
Article History: Received: 2026/01/05 Review: 2026/04/28 Accepted: 2026/05/03	Bread is one of the most essential food items in the Iranian diet and plays a critical role in providing daily energy intake and ensuring food security. However, high levels of bread waste and fluctuations in bread quality remain major challenges throughout the production and consumption chain of this strategic food product. The present study aimed to investigate the effects of human-related factors and physical bakery conditions on the sensory quality of machine-made Taftoon bread, which is the most commonly consumed traditional bread in Iran. In this study, data were collected from 15 selected bakeries that received the same type of flour on the same day to eliminate the effect of flour quality variability. Information related to human capital characteristics, bakery conditions, and equipment status was obtained through field surveys. Simultaneously, bread samples were collected from each bakery and evaluated for sensory quality by semi-trained panelists using a five-point hedonic scale. To achieve an integrated analysis, in addition to descriptive statistics and correlation analysis, two composite indices—the Human Capital Index (HCI) and the Bakery Condition Index (BCI)—were calculated. The results showed that the sensory quality scores of breads ranged from 2.71 to 4.00. Correlation and regression analyses revealed a strong and statistically significant relationship between the Human Capital Index and bread sensory quality ($R^2 = 0.79$), whereas the Bakery Condition Index exhibited a weaker association with bread quality ($R^2 = 0.31$). These findings highlight the critical role of bakers' experience, skills, and job satisfaction in improving bread quality and reducing bread waste. The results provide valuable insights for policymakers and stakeholders aiming to enhance bread quality and optimize waste management strategies in the bakery sector.
Keywords: Bread quality, traditional bread, Human capital, Bakery conditions, Bread waste	
DOI: 10.48311/fsct.2026.118650.83025 *Corresponding Author E- Falsafi@areeo.ac.ir	

1-Introduction

Bread is the principal staple food in Iranian households and plays a crucial role in ensuring both energy intake and food security. Supplying bread for a population exceeding 90 million people requires the involvement of a wide range of activities across the agricultural sector, food processing industries, transportation, storage, and distribution systems [1]. Food consumption patterns indicate that, on average, approximately 46% of the daily energy intake of urban populations and nearly 60% of that of rural populations is derived from bread consumption. This substantial dependence means that any disruption in bread quality, distribution, or flour allocation can directly affect the livelihood and welfare of a large segment of society [2].

Despite its importance, bread waste remains one of the major challenges facing the national food system. Reports suggest that, in some cases, up to 30% of produced bread is lost as waste [3]. This occurs despite the considerable financial resources allocated annually by the government to subsidize wheat and flour production. According to official statistics, subsidies for this sector amount to approximately 300 trillion Iranian rials per year. Given the scale of these subsidies, bread waste represents not only a food security concern but also a significant economic burden, as a substantial portion of public financial resources is effectively lost [4]. Under current national conditions and considering the necessity of safeguarding food security for different socioeconomic groups, reducing food waste—particularly bread waste—may be even more important than increasing the production of primary agricultural commodities. This issue becomes more evident when considering that, although Iran accounts for approximately 1% of the global population, it consumes nearly 2.5% of the world's wheat production, a discrepancy that may be partly attributable to substantial losses throughout the bread supply chain [5].

Bread waste is a multifactorial phenomenon influenced by numerous factors associated with production, distribution, and consumption. Among these, bakeries, as the final stage of production, play a particularly important role. Factors such as flour quality, hygienic conditions, flour storage practices, equipment age and performance, and human-related factors—including workers' experience, technical knowledge, skills, and training—can directly affect bread quality and consequently influence the level of waste generated. In addition, consumer behavior and consumption patterns also contribute significantly to bread wastage [6].

Several studies in Iran have investigated bread waste and its determining factors. Mahdii et al. reported that inadequate supervision of bakery operations, unrealistic flour pricing policies, and insufficient skills and expertise among bakers were among the most important contributors to bread waste in Bahar County [7]. In another study, Karbasi et al., focusing on urban and rural households in Sistan and Baluchestan Province, demonstrated that bread waste was positively associated with bread purchasing frequency, the number of visits to bakeries, and the time spent obtaining bread. However, bread quality and bakery conditions were not directly assessed in that study [8]. Likewise, Zarin-Ghalami et al., in an investigation conducted in Zanjan County, identified insufficient fermentation time, outdated baking equipment, and limited technical knowledge among bakers as major factors contributing to increased bread waste [9].

Given the critical role of bakeries in determining bread quality and waste generation, the present study aimed to systematically evaluate human-related factors and infrastructural conditions in bakeries and to investigate their relationship with the quality of the bread produced. To achieve this objective, a field survey was conducted using questionnaire-based data collection and sensory

evaluation of bread samples. Two composite indices, namely the *Bakery Human Capital Index* and the *Bakery Infrastructure Index*, were developed and calculated to enable an integrated and comparable assessment of bakery performance. The use of these indices, together with correlation analyses of individual and structural variables, provides a quantitative framework for assessing the relative contribution of human and environmental factors to bread quality. By moving beyond traditional single-variable and descriptive approaches, this study seeks to introduce practical composite indicators that can serve as effective tools for policymaking, bakery performance monitoring, and the design of targeted training programs. The findings may support more informed decision-making aimed at improving bread quality, reducing waste, and optimizing the utilization of subsidized resources within the national bread supply chain.

2- Materials and Methods

2.1. Study Design and Data Collection

This study was conducted as a descriptive–analytical field investigation. Data were collected from 15 bakeries producing machine-made Taftoon bread within the study area through questionnaire-based surveys and bread sampling. The bakeries were selected in coordination with the local Grain and Commercial Services Administration to ensure that all participating bakeries had received the same type of flour on the same day. This approach was adopted to minimize the potential effects of flour type and delivery time on bread quality and to improve the comparability of the results.

The questionnaire consisted of a series of structured questions covering workforce characteristics, bakery physical and operational conditions, and selected performance indicators. The surveyed variables included the number of employees, baker's educational level, baker's work experience, apprentice

baker's experience and skill level, participation in relevant training programs, building conditions, sanitary status of the premises and equipment, flour storage practices, daily flour allocation, dough fermentation time, age of baking equipment, number of customers, baker's job satisfaction, and satisfaction with the quality of the supplied flour.

Questionnaire responses were obtained through a combination of self-reporting by bakery personnel and direct observations conducted by the researchers. To facilitate statistical analysis, qualitative responses were converted into numerical values. Binary variables were coded using a 0–1 scale, ordinal variables were coded using a five-point Likert scale, and quantitative variables were recorded using their actual values (e.g., years, counts, or quantities).

To evaluate bread quality, bread samples were collected from each bakery. Following transportation to the laboratory, sensory properties were assessed by seven semi-trained panelists using a five-point hedonic scale. The evaluated attributes included texture, color, appearance, aroma, and overall acceptability [10].

2.2. Calculation of the Human Capital and Bakery Condition Indices

To model the influence of human and infrastructural factors on bread quality and to reduce variable complexity in the statistical analyses, two composite indices were developed: the Human Capital Index (HCI) and the Bakery Condition Index (BCI).

The Human Capital Index was designed to represent workforce-related characteristics within each bakery. Variables included in this index were baker's educational level, baker's work experience, apprentice baker's experience and skill level, number of employees, and job satisfaction. Together, these variables reflect the knowledge, experience, skills, and motivation of bakery personnel.

The Bakery Condition Index was developed to assess the physical and sanitary conditions of bakery facilities and equipment. Variables incorporated into this index included building conditions, sanitary status of the premises and equipment, flour storage practices, and hygienic condition of baking equipment. These variables collectively represent the infrastructural and operational environment of the bakery.

For the calculation of both composite indices, the constituent variables were first standardized using the Z-score normalization method based on the mean and standard deviation of the dataset, thereby eliminating the effects of differing measurement scales. Subsequently, the standardized values were aggregated to obtain a final index score for each bakery. Higher index values were interpreted as indicating more favorable human capital or bakery conditions. The resulting indices were then used to examine their relationships with the sensory quality of bread.

2.3. Statistical Analysis

Following data collection and coding, all statistical analyses were performed using the R statistical software environment. Correlation analysis was conducted to examine relationships among quantitative variables and to assess the associations between the composite indices (HCI and BCI) and bread sensory quality scores. Correlation coefficients were used as measures of the strength and direction of relationships among variables.

To provide a graphical representation of the correlation structure among the studied variables, a correlation heat map was generated. Statistical significance was determined at a significance level of $P < 0.05$ for all analyses.

3-Results and Discussion

Analysis of the questionnaire data revealed that several of the investigated variables exhibited no variation across the surveyed bakeries, making statistical analysis and correlation

assessment with bread quality impossible. Nevertheless, these findings remain noteworthy from an analytical perspective and warrant discussion.

None of the bakers included in this study had participated in any bakery-related training courses. This finding is consistent with the results reported by Zarin-Ghalami et al., who observed that most bakeries and bakery workers in Zanjan lacked formal scientific training and specialized bakery education. The persistence of this pattern across different regions of the country highlights a substantial gap in the training and capacity-building systems for human resources employed in the bakery sector. Similarly, Hasheminejad et al. (2016), in their investigation of bread supply chain management strategies for reducing bread waste, identified the absence of skill-development programs as a critical weakness within bakery operations. They recommended that all personnel involved in bread production should complete certified training programs and obtain the necessary professional qualifications before entering the industry [11].

All participating bakers also reported that the quality of the flour supplied to bakeries was not consistent over time and that noticeable variations existed among flour batches. Although the present study controlled for flour quality by selecting bakeries that received the same flour type on the same day, bakers' perceptions regarding flour quality fluctuations are noteworthy. In this regard, Abdollahzadeh (2016) reported seasonal variations in flour quality in Sabzevar County, with flour supplied during the summer exhibiting lower quality than flour delivered during the spring and autumn seasons [12]. Such fluctuations may contribute to variations in bread quality and should be considered in future quality improvement programs.

Another important finding was the lack of awareness among all surveyed bakers regarding proper household bread storage practices aimed at minimizing bread waste. Furthermore, none

of the participants were aware of national wheat production levels, the proportion of wheat used for bread production, the magnitude of bread waste, or the associated economic burden imposed on the government. This lack of awareness may diminish the perceived value of bread among bakery workers and consequently reduce their motivation to actively participate in waste-reduction efforts. In agreement with this observation, Mahdii et al. (2012) emphasized the importance of cultural and educational

factors in bread waste management, arguing that insufficient public awareness and inadequate educational initiatives concerning the strategic importance of wheat and bread can contribute significantly to increasing bread waste [7]. The findings of the present study support this perspective and underline the importance of educational and awareness-raising programs as practical strategies for reducing bread waste.

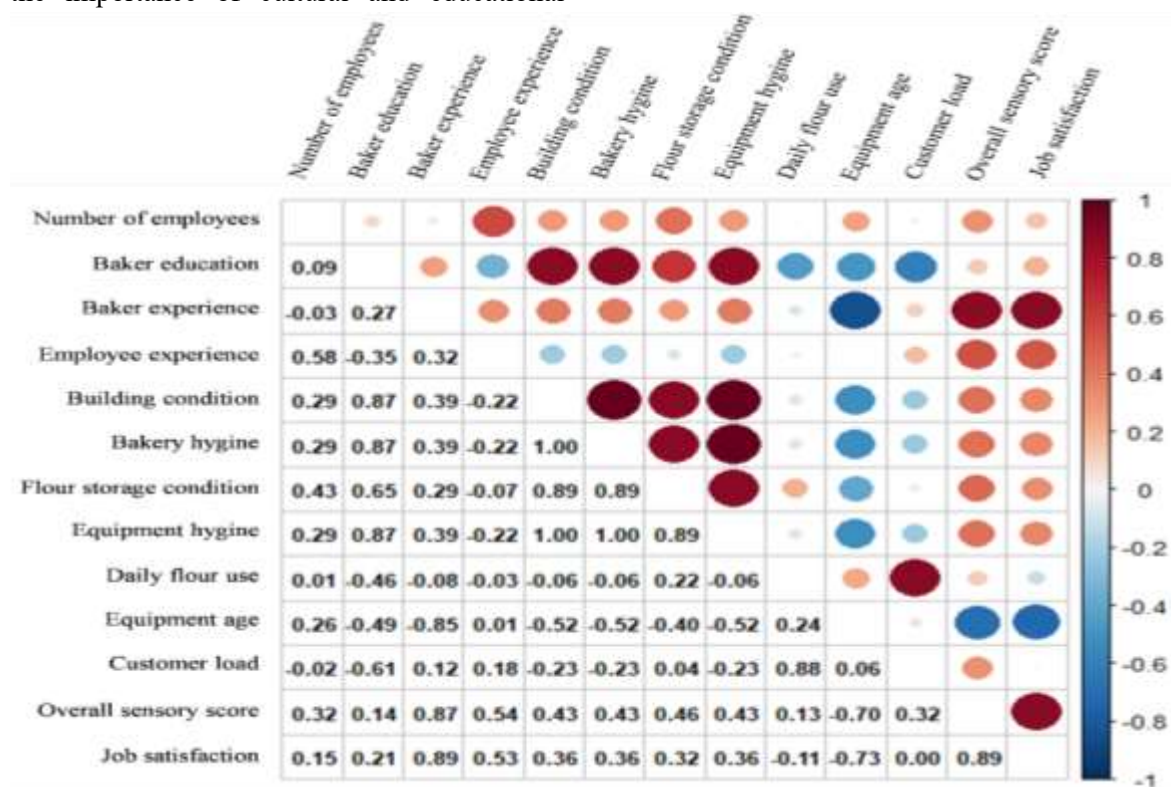


Figure 1- Correlation heat map of relationships among bakery operational factors and bread quality

3.1. Correlation Pattern Among Factors Affecting Bread Quality

The correlation analysis presented as a heat map (Figure 1) demonstrated that the sensory quality of bread was influenced by a combination of human and infrastructural factors, although the strength of these relationships varied considerably among variables.

Among the human-related variables, the baker's work experience exhibited the strongest positive correlation with bread sensory quality

($r = 0.87$). This finding highlights the critical role of practical experience in managing production processes, controlling fermentation and baking conditions, and ultimately improving bread quality. Examination of the boxplot distribution (Figure 2) further revealed substantial variability in bakers' experience, with a relatively wide range and a median located in the upper portion of the distribution. This pattern indicates that a considerable proportion of the surveyed bakers possessed extensive professional experience. In addition, baker experience showed a strong positive correlation with job satisfaction ($r = 0.89$),

suggesting a potential interaction between professional expertise and occupational motivation in determining bakery performance.

Similarly, the work experience of bakery assistants was positively associated with bread quality ($r = 0.54$), emphasizing that bread quality depends not only on the baker but also on the competence of supporting personnel. Consistent with these findings, Abdollahzadeh (2016) identified the professional skills and technical expertise of bakery workers as the most influential determinants of bread quality in bakeries operating in Sabzevar County [12].

In contrast, the age of baking equipment exhibited a substantial negative correlation with bread sensory quality ($r = -0.70$). This result suggests that equipment deterioration may reduce process stability and negatively affect the final quality of bread. Talebi (2014), in an assessment of the Iranian bakery industry, identified process mechanization as one of the most important factors contributing to bread quality improvement. According to the author, advanced equipment enables more precise control of ingredient quality, processing conditions, temperature, and baking time while reducing human error, thereby improving product quality [13]. Likewise, Zarin-Ghalami et al. (2013) reported that more than 50% of baking equipment used in bakeries in Zanjan County had been in operation for over ten years and emphasized the adverse effects of equipment aging on bread quality [9]. Furthermore, Parizad et al. (2008) estimated the useful service life of bakery baking equipment to be approximately 8–10 years [14].

The distribution of baking equipment age in the present study (Figure 2) was skewed toward higher values, with both the median and third quartile occurring within relatively advanced age ranges. These findings indicate that a substantial proportion of bakeries were operating with aging equipment that had exceeded the recommended service life. The considerable spread between quartiles further reflects substantial heterogeneity in equipment

conditions among bakeries and may partly explain the observed variability in bread quality.

The age of baking equipment also exhibited negative correlations with both baker experience ($r = -0.85$) and job satisfaction ($r = -0.73$), suggesting that bakeries operating with older equipment may face both technical and motivational challenges. From the perspective of physical and sanitary conditions, bakery building conditions, hygiene status of the premises and equipment, and flour storage practices all showed moderate positive correlations with bread quality (r ranging from 0.43 to 0.46). These findings indicate that adherence to hygienic standards and the availability of adequate infrastructure may contribute to improvements in bread quality.

No significant relationships were observed between bread quality and variables associated with bakery production scale, including daily flour consumption and number of customers. This finding suggests that production volume and market demand alone are not primary determinants of bread quality; rather, quality appears to be more strongly influenced by process management and workforce competence. Similarly, Alami et al. (2014) reported that the quality of traditional breads produced in Gonabad County was largely dependent on human-related factors such as the skills of bakers and bakery assistants and their precision in dough preparation, fermentation, and baking operations [15]. However, Arslanbod et al. (2000) reported that increasing production volume in bakeries in Urmia was associated with a decline in bread quality and an increase in bread waste [16].

Overall, the correlation pattern observed in the present study suggests that human-related factors, particularly baker experience, job satisfaction, and workforce skills, together with equipment condition and bakery infrastructure, are among the most influential factors associated with bread quality. In contrast,

quantitative indicators related to production scale appear to play a comparatively minor role.

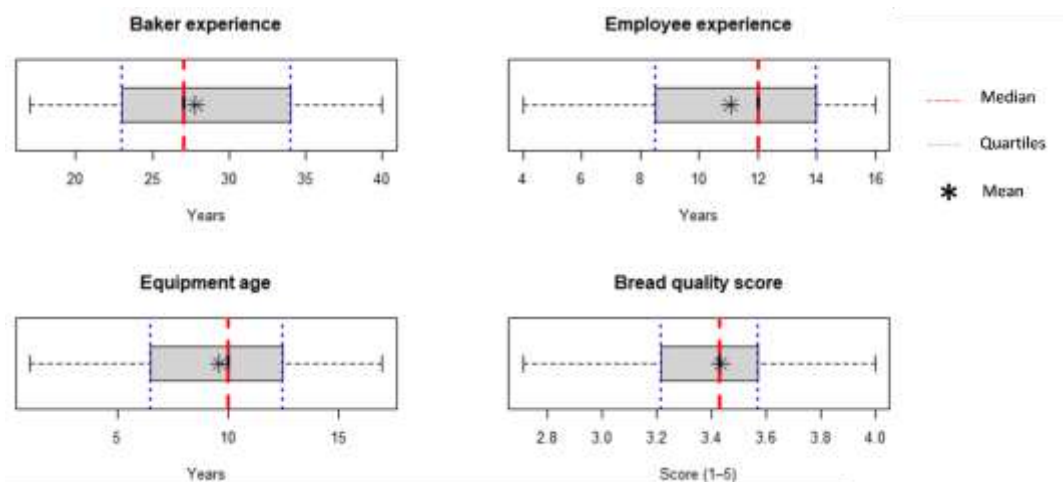


Figure 2- Box plots indicating the distribution of bakers attributes in different quartiles

3.2. Analysis of the Human Capital and Bakery Condition Indices

To evaluate the relative importance of human-related and physical factors in determining bread quality, two composite indices were calculated: the Human Capital Index (HCI) and the Bakery Condition Index (BCI). The HCI was constructed using variables including the baker's educational level, work experience, assistant baker's experience and skill level, number of employees, and job satisfaction. The BCI was calculated using indicators related to bakery building conditions, sanitary status of the premises and equipment, flour storage practices, and hygiene conditions of baking equipment.

The calculated HCI and BCI values for the 15 surveyed bakeries are presented in Figure 3. The results revealed considerable heterogeneity among bakeries with respect to both indices. The wide range of positive and negative values indicates substantial differences in workforce characteristics as well as physical and sanitary conditions across production units. Negative index values represent performance below the overall sample mean, whereas positive values indicate more favorable conditions. These findings suggest that even when bakeries

receive the same type of flour under similar conditions, the final quality of bread may vary substantially due to factors internal to the bakery environment. Similarly, Arslanbod et al. reported that workforce experience was one of the most important factors influencing bread waste in bakeries in Urmia, with bakeries employing more experienced personnel exhibiting significantly lower levels of bread waste [16].

To further examine the influence of these composite indices on bread quality, relationships between HCI, BCI, and sensory quality scores were analyzed using scatter plots and linear regression models (Figure 4). As shown in Figure 4, the Human Capital Index exhibited a substantially stronger association with bread sensory quality than the Bakery Condition Index. The regression model yielded a coefficient of determination (R^2) of 0.79, indicating that a large proportion of the variability in bread sensory quality could be explained by workforce-related characteristics. Factors such as baker and assistant experience, educational level, workforce size, and job satisfaction may influence process control, fermentation management, baking consistency, and ultimately the sensory quality of the final product.

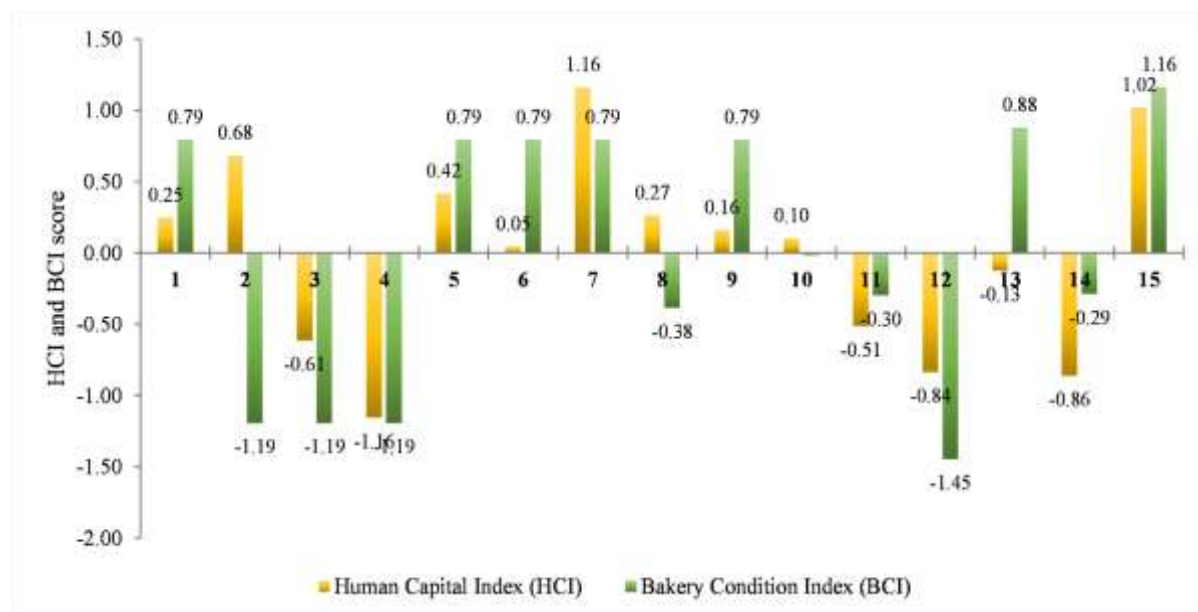
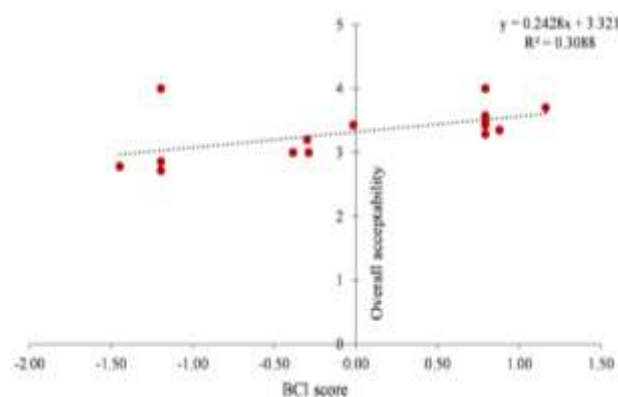


Figure 3- Composite Human Capital Index (HCI) and Bakery Condition Index (BCI) calculated for the studied bakeries

In contrast, the Bakery Condition Index showed a weaker relationship with bread sensory quality, with an R^2 value of 0.3088 (Figure 4). Although building conditions, hygiene practices, flour storage, and equipment status are recognized as important factors in bread production, the results suggest that their contribution to explaining variations in sensory quality was lower than that of human capital variables.



Overall, the analysis of the composite indices indicates that human capital may play a more influential role than physical bakery conditions in determining bread quality. These findings highlight the importance of workforce training, skill development, awareness enhancement, and job satisfaction as practical approaches for improving bread quality and reducing bread waste. Notably, such human-centered interventions have often received less attention in policy frameworks than investments in equipment and infrastructure.

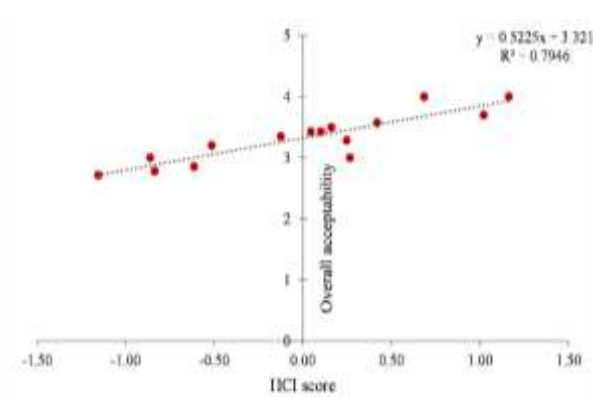


Figure 4- Relationship between HCI/BCI and sensory quality score of bread

4- Conclusion

This study investigated the influence of human-related and physical bakery factors on the

sensory quality of machine-made Taftoon bread. Sensory evaluation results showed that bread quality scores ranged from 2.71 to 4.00 on a five-point hedonic scale, indicating

substantial variability in product quality despite the use of the same flour type delivered under similar conditions.

Correlation analysis and heat-map visualization revealed that workforce-related variables, particularly baker experience, assistant baker experience, and job satisfaction, exhibited stronger positive associations with bread sensory quality. In contrast, certain structural variables, most notably the age of baking equipment, showed a considerable negative correlation with bread quality ($r \approx -0.70$). These findings suggest that both human and infrastructural factors contribute to bread quality; however, workforce characteristics appear to play a more prominent role.

To provide a more comprehensive assessment, two composite indices—the Human Capital Index (HCI) and the Bakery Condition Index (BCI)—were developed and evaluated. Regression analysis demonstrated that HCI was strongly associated with bread sensory quality ($R^2 = 0.79$), whereas BCI explained a considerably smaller proportion of quality variation ($R^2 = 0.31$). This marked difference highlights the importance of workforce experience, technical skills, and job satisfaction in achieving high-quality bread production.

In conclusion, the results suggest that improvements in bread quality and reductions in bread waste cannot be achieved solely through equipment modernization and infrastructure upgrades. Equal, if not greater, emphasis should be placed on workforce training, professional development, and the enhancement of bakers' occupational status and motivation. These findings provide valuable evidence for policymakers seeking to improve bread quality and reduce waste throughout the national bread supply chain.

Data Availability

Data will be made available on request

Conflict of Interest

None

Funding Statement

None

Authors Contributions

Falsafi: Project administration, writing, review, editing; Gorouee: Project development.

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مقاله علمی-پژوهشی

بررسی نقش عوامل انسانی و زیرساختی نانوائی‌ها بر کیفیت نان: مطالعه موردی در شهرستان دزفول

سید رضا فلسفی^{۱*}، رامین گوروئی^۲

۱- استادیار پژوهش بخش تحقیقات فنی و مهندسی کشاورزی، مرکز تحقیقات و آموزش کشاورزی و منابع طبیعی دزفول (صفی آباد)، سازمان تحقیقات، آموزش و ترویج کشاورزی، خوزستان، ایران

۲- کارشناس پژوهش بخش تحقیقات فنی و مهندسی کشاورزی، مرکز تحقیقات و آموزش کشاورزی و منابع طبیعی دزفول (صفی آباد)، سازمان تحقیقات، آموزش و ترویج کشاورزی، خوزستان، ایران

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شرایط نانوائی،

ضایعات نان

نان به عنوان یکی از اصلی ترین اقلام غذایی در سبد مصرفی خانوارهای ایرانی، نقش بسزایی در تأمین انرژی روزانه و امنیت غذایی جامعه دارد. با این حال، ضایعات بالای نان و نوسان کیفیت آن، همچنان یکی از چالش های مهم در زنجیره تولید و مصرف این محصول راهبردی محسوب می شود. پژوهش حاضر با هدف بررسی اثر عوامل انسانی و شرایط فیزیکی نانوائی بر کیفیت حسی نان تافتون ماشینی، به عنوان رایج ترین نوع نان سنتی در ایران، انجام شد. در این مطالعه، با مراجعه به ۱۵ نانوائی منتخب که در یک روز مشخص و از یک نوع آرد یکسان استفاده می کردند، داده های مربوط به ویژگی های نیروی انسانی، شرایط نانوائی و تجهیزات جمع آوری شد. هم زمان، نمونه نان از هر نانوائی تهیه و کیفیت حسی آن توسط ارزیابان نیمه آموزش دیده و با استفاده از آزمون هدونیک پنج نقطه ای ارزیابی گردید. به منظور تحلیل جامع داده ها، علاوه بر تحلیل های توصیفی و همبستگی، دو شاخص ترکیبی شامل شاخص سرمایه انسانی نانوائی و شاخص وضعیت نانوائی محاسبه شد. نتایج نشان داد که امتیاز کیفیت حسی نان در بازه ۲/۷۱ تا ۴ متغیر بود. تحلیل همبستگی و رگرسیون بیانگر ارتباط قوی و معنادار شاخص سرمایه انسانی با کیفیت حسی نان ($R^2 = 0.79$) بود، در حالی که شاخص وضعیت نانوائی ارتباط ضعیف تری با کیفیت نان نشان داد ($R^2 = 0.31$). یافته های این پژوهش بر اهمیت نقش تجربه، مهارت و رضایت شغلی نانوائیان در بهبود کیفیت نان و کاهش ضایعات آن تأکید دارد و می تواند مبنایی برای سیاست گذاری های هدفمند در صنعت نان کشور باشد

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* مسئول مکاتبات:

Falsafi@areeo.ac.ir