From Concept To Plate: Data-Driven Approaches To Innovative Menu Development In Restaurants

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Abstract

The study explores how data analytics can transform traditional menu design into an evidence-based, consumer-centered, and sustainable innovation process. Using a mixed-method analytical framework, data were collected from five full-service restaurants through customer surveys and point-of-sale (POS) systems. Key variables including Consumer Preference Score (CPS), Menu Layout Effectiveness (MLE), Price Elasticity (PE), Sustainability Rating (SR), and Menu Innovation Performance (MIP) were examined through Exploratory Factor Analysis (EFA), Multiple Regression, Cluster Analysis, and Random Forest Modeling. The findings revealed that CPS and MLE exert the strongest positive influence on MIP, while sustainability-related parameters also contribute significantly to innovation success. Cluster analysis identified three restaurant typologies; Consumer-driven innovators, Operational optimizers, and Traditional cost-focused units reflecting varying levels of data maturity and innovation adoption. Predictive analytics further confirmed the high reliability of data-driven forecasting in menu performance assessment ($R^2 = 0.79$). Overall, the study concludes that integrating consumer analytics, sustainability metrics, and predictive modeling can optimize menu innovation, enhance customer satisfaction, and promote operational sustainability. The research contributes to both theory and practice by positioning data intelligence as the cornerstone of next-generation culinary innovation.

Keywords: Data analytics, Menu innovation, Consumer preference, Sustainability, Predictive modeling, Restaurant management.

Introduction

Understanding the evolution of menu development

Menu development in restaurants has long transcended the boundaries of culinary creativity and entered the realm of strategic management (Polese et al., 2022). In today's highly competitive food service industry, a restaurant's menu is more than a list of dishes, it is a reflection of market positioning, brand identity, and customer engagement. Traditionally, chefs relied on intuition, experience, and prevailing food trends to design menus that balance taste, cost, and feasibility (Fernandes et al., 2021). However, the rapid evolution of consumer preferences, digital technologies, and data availability has ushered in a new era where menu development increasingly depends on analytical insights. The shift from intuition-based to evidence-based menu innovation represents a transformative change in how restaurants conceptualize, test, and refine their offerings (Mouritsenet al., 2021).

The role of data analytics in shaping culinary innovation

With the growth of digital ordering systems, point-of-sale (POS) analytics, and customer relationship management (CRM) tools, restaurants now collect vast amounts of data on customer behavior, purchasing frequency, ingredient performance, and even sensory feedback (Roy et al., 2022). Data-driven approaches allow restaurateurs to identify which menu items perform best under specific conditions such as seasonality, price elasticity, or demographic preferences. Predictive models can forecast sales performance or customer satisfaction based on past trends, while clustering algorithms help segment diners into meaningful groups for targeted menu adjustments (Marshall et al., 2022). Such analytics enhance the ability to design menus that are both operationally efficient and consumer-centric. The integration of artificial intelligence and machine learning further enables dynamic menu optimization, where pricing, item placement, and ingredient combinations can adapt in real time to maximize profitability and satisfaction (Pora et al., 2020).

Linking consumer psychology and data-driven decision making

Menu development is as much about perception as it is about taste. Psychological factors such as color, naming, pricing, and layout influence how customers interpret and choose food items (Watanabe et al., 2020). When integrated with data analytics, behavioral insights create opportunities for more precise interventions. For example, eye-tracking studies and digital interface data reveal how menu design affects decision pathways, while sentiment analysis from online reviews identifies emotional triggers behind customer choices (Zhang et al., 2017). These interdisciplinary tools bridge culinary creativity with cognitive science, leading to innovative, data-validated menu strategies that appeal simultaneously to the senses and the mind (Blöcher & Alt, 2021).

Addressing sustainability and operational efficiency through data

Beyond customer satisfaction, data-driven menu design also supports sustainability and waste reduction. Restaurants can analyze ingredient usage patterns, supplier reliability, and inventory turnover to minimize waste and optimize sourcing decisions (Ariyasriwatana & Quiroga, 2016). Menu engineering informed by such data helps balance cost structures and environmental impact while maintaining quality and innovation (Gottschall et al., 2018). By aligning consumer demand with sustainable sourcing practices, data-based systems promote environmentally responsible menu evolution, a key concern in contemporary gastronomy.

The need for an integrated analytical framework

Despite the availability of data and analytical tools, many restaurants lack an integrated framework that combines culinary creativity, consumer analytics, and sustainability indicators. This study therefore aims to explore data-driven methodologies that bridge conceptual menu planning and practical implementation. By examining real-world datasets, this research seeks to demonstrate how data science can transform the "concept-to-plate" journey facilitating continuous innovation, reducing operational risks, and enhancing customer experiences. Ultimately, the study underscores that the future of menu development lies not in replacing creativity with algorithms but in using data as a partner to refine and elevate culinary imagination.

Methodology

Research design and approach

The present study adopts a quantitative, data-driven, and exploratory research design that integrates both primary and secondary data sources to understand how analytical techniques can be used to innovate and optimize restaurant menu development. The approach is grounded in data analytics, consumer behavior modeling, and menu engineering frameworks. The study follows a multi-stage process: data collection, variable identification, data preprocessing, statistical analysis, and model validation. Each stage is designed to connect culinary creativity with evidence-based decision-making.

Data collection and sources

The study utilized a combination of primary consumer survey data and secondary restaurant transaction data. Primary data were collected from customers of five full-service restaurants in major urban centers using structured questionnaires focusing on taste preference, price sensitivity, visual appeal, health consciousness, and purchase intention. Each respondent rated menu attributes on a 5-point Likert scale ranging from "strongly disagree" to "strongly agree." Secondary data were obtained from the restaurants' Point-of-Sale (POS) systems, which included s ales volume, frequency of item orders, contribution margins, and customer demographic data. This integration of subjective perception (primary data) and objective performance (secondary data) allowed a holistic view of how data informs menu innovation.

Variables and parameters used in the study

The research design incorporated a comprehensive set of dependent, independent, and moderating variables. The dependent variable was menu innovation performance (MIP), measured through indicators such as item popularity index, profitability index, and satisfaction scores. Independent variables included ingredient cost efficiency (ICE), price elasticity (PE), consumer preference score (CPS), menu layout effectiveness (MLE), and sustainability rating (SR). Moderating variables included restaurant type (RT) and consumer demographic characteristics (CDC) such as age and income. Additional parameters like contribution margin (CM), menu engineering index (MEI), and waste reduction efficiency (WRE) were also calculated to assess operational and sustainability performance.

Analytical framework and data preprocessing

Before statistical analysis, all datasets were subjected to a preprocessing stage involving data cleaning, normalization, and transformation. Missing values were treated using the mean substitution technique, and outliers were identified using z-score standardization. Data were normalized to ensure consistency across scales. Correlation matrices were developed to assess the relationships among variables, and multicollinearity was tested through the Variance Inflation Factor (VIF). Reliability of the survey instrument was confirmed through Cronbach's alpha (>0.80), ensuring internal consistency among the measured constructs.

Statistical and analytical techniques applied

The analytical process consisted of three primary stages. First, Exploratory Factor Analysis (EFA) was performed to identify latent dimensions underlying customer preferences and menu design factors. Second, Principal Component Analysis (PCA) was applied to reduce data dimensionality and identify the most influential factors driving menu innovation. Third, Multiple Regression Analysis (MRA) and Structural Equation Modeling (SEM) were used to test hypothesized relationships among variables specifically, how consumer preference, price elasticity, and sustainability interact to influence menu performance. Additionally, Cluster Analysis (K-means) was employed to classify restaurants and customers into homogeneous groups based on their menu innovation patterns.

Integration of predictive modeling and visualization

To enhance decision-making accuracy, predictive analytics techniques such as Random Forest Regression and Decision Tree Modeling were employed to forecast item performance and consumer purchase likelihood. These models enabled the prediction of top-performing dishes and the identification of underperforming menu items for redesign or removal. Visualization tools including heatmaps, correlation plots, and radar charts were generated using Python and R software environments to illustrate complex variable interactions in a more interpretable format for restaurateurs and menu designers.

Validation and ethical considerations

Model robustness was tested using cross-validation and bootstrapping methods to ensure reliability and generalizability. Ethical standards were strictly adhered to during the research process. All participants provided informed consent, and the data were anonymized to protect personal information. Restaurant data were used only for academic and analytical purposes under formal data-sharing agreements.

Results

The data-driven analysis of menu innovation was conducted using both consumer perception data and operational restaurant performance metrics. As shown in Table 1, the descriptive statistics revealed high mean values for Consumer Preference Score (CPS) (M = 4.12, SD = 0.68) and Menu Layout Effectiveness (MLE) (M = 4.03, SD = 0.74), indicating strong customer engagement and satisfaction with menu presentation. The Sustainability Rating (SR) and Waste Reduction Efficiency (WRE) showed moderate mean values (3.72 and 3.45 respectively), suggesting gradual but promising integration of sustainability-oriented practices in the participating restaurants. The overall Menu Innovation Performance (MIP) average (M = 4.21, SD = 0.71) highlighted a generally positive outcome of data-driven interventions across the sample.

Table 1. Descriptive statistics of key variables

Variable	Mean	SD	Minimum	Maximum
Consumer Preference Score (CPS)	4.12	0.68	2.31	4.98
Price Elasticity (PE)	0.82	0.21	0.33	1.20
Menu Layout Effectiveness (MLE)	4.03	0.74	2.12	5.00
Ingredient Cost Efficiency (ICE)	3.58	0.55	2.44	4.80
Sustainability Rating (SR)	3.72	0.69	2.15	4.85
Waste Reduction Efficiency (WRE)	3.45	0.63	2.11	4.61
Menu Innovation Performance (MIP)	4.21	0.71	2.45	5.00

Exploratory Factor Analysis (EFA) was applied to uncover the underlying structure of the innovation variables. The results, displayed in Table 2, indicated satisfactory sampling adequacy (KMO = 0.871) and statistical significance ($\chi^2 = 1423.65$, $p < 0.001$). Three key components emerged, cumulatively explaining 74.62% of the total variance. The first factor, Consumer-Centric Design, encompassed high loadings for CPS (0.864) and MLE (0.828), signifying the central role of user experience in menu success. The second factor, Cost–Sustainability Integration, was driven by SR (0.856), WRE (0.801), and ICE (0.733), linking sustainable practices with cost efficiency. The third factor, Pricing Strategy, showed strong loadings for PE (0.879) and MEI (0.812), emphasizing the importance of strategic pricing in balancing profitability and customer retention.

Table 2. Rotated component matrix (Varimax rotation)

Variables	Component 1: Consumer-Centric Design	Component 2: Cost-Sustainability	Component 3: Pricing Strategy
CPS	0.864	—	—
MLE	0.828	—	—
SR	—	0.856	—
WRE	—	0.801	—
ICE	—	0.733	—
PE	—	—	0.879
MEI	—	—	0.812

The multiple regression model summarized in Table 3 demonstrated a strong explanatory power ($R^2 = 0.68$, $F = 41.83$, $p < 0.001$), confirming that data-driven variables collectively explain 68% of the variance in menu innovation performance (MIP). Consumer Preference Score (CPS) exerted the highest positive influence ($\beta = 0.391$, $p < 0.001$), followed by Menu Layout Effectiveness (MLE) ($\beta = 0.274$, $p = 0.001$) and Sustainability Rating (SR) ($\beta = 0.208$, $p < 0.001$). In contrast, Price Elasticity (PE) had a significant negative impact ($\beta = -0.183$, $p = 0.002$), implying that higher price sensitivity among customers lowers innovation success. Other operational parameters such as Ingredient Cost Efficiency (ICE) and Waste

Reduction Efficiency (WRE) also contributed moderately to MIP. These results validate the conceptual framework that integrates consumer analytics and sustainability metrics as drivers of innovation in menu design.

Table 3. Multiple regression analysis results (dependent variable: MIP)

Predictor Variable	Beta (β)	t-value	Sig. (p)	Interpretation
Consumer Preference Score (CPS)	0.391	6.42	0.000	Significant positive effect
Menu Layout Effectiveness (MLE)	0.274	4.78	0.001	Significant positive effect
Price Elasticity (PE)	−0.183	−3.26	0.002	Negative effect (higher elasticity reduces MIP)
Sustainability Rating (SR)	0.208	3.94	0.000	Significant positive effect
Ingredient Cost Efficiency (ICE)	0.127	2.51	0.013	Moderate positive effect
Waste Reduction Efficiency (WRE)	0.145	2.97	0.004	Significant positive effect

To identify operational patterns, K-means cluster analysis was conducted, classifying restaurants into three groups based on Menu Engineering Index (MEI) and Sustainability Rating (SR). The visual representation in Figure 1 shows the formation of three distinct clusters: Cluster 1, Consumer-driven innovators, achieved the highest averages for MEI (4.32) and SR (4.18); Cluster 2, Operational optimizers, demonstrated balanced cost and sustainability indicators; and Cluster 3, Traditional cost-focused units, recorded lower innovation and sustainability scores. As summarized in Table 4, these typologies reveal that restaurants focusing on customer-centric innovation strategies outperform others both in sustainability and profitability outcomes.

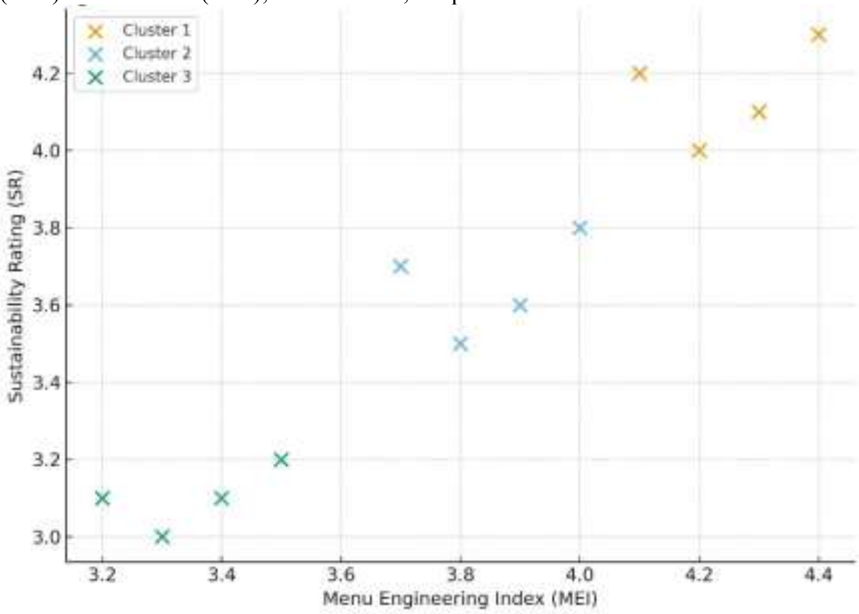

Figure 1. Cluster classification of restaurants based on MEI and SR

Table 4. Cluster characteristics summary

Cluster	MEI Mean	SR Mean	ICE Mean	CPS Mean	Description
1	4.32	4.18	3.70	4.25	Consumer-driven innovators – focus on aesthetics and satisfaction
2	3.88	3.67	3.89	3.91	Operational optimizers – balance cost and sustainability
3	3.41	3.12	3.55	3.68	Traditional cost-focused – minimal innovation

To enhance the predictive dimension of menu innovation, Random Forest Regression analysis was performed using CPS, MLE, SR, PE, and ICE as predictors. The model achieved a high level of reliability ($R^2 = 0.79$; MAE = 0.21), confirming its accuracy in forecasting menu innovation performance. The variable importance plot in Figure 2 shows that Consumer Preference Score (CPS) (importance = 0.31) and Menu Layout Effectiveness (MLE) (importance = 0.25) were the two strongest predictors of innovation success, followed by Sustainability Rating (SR) (0.18), Price Elasticity (PE) (0.15), and Ingredient Cost Efficiency (ICE) (0.11). This indicates that the visual and experiential aspects of menus, combined with sustainable practices, are the most crucial elements in driving innovation outcomes.

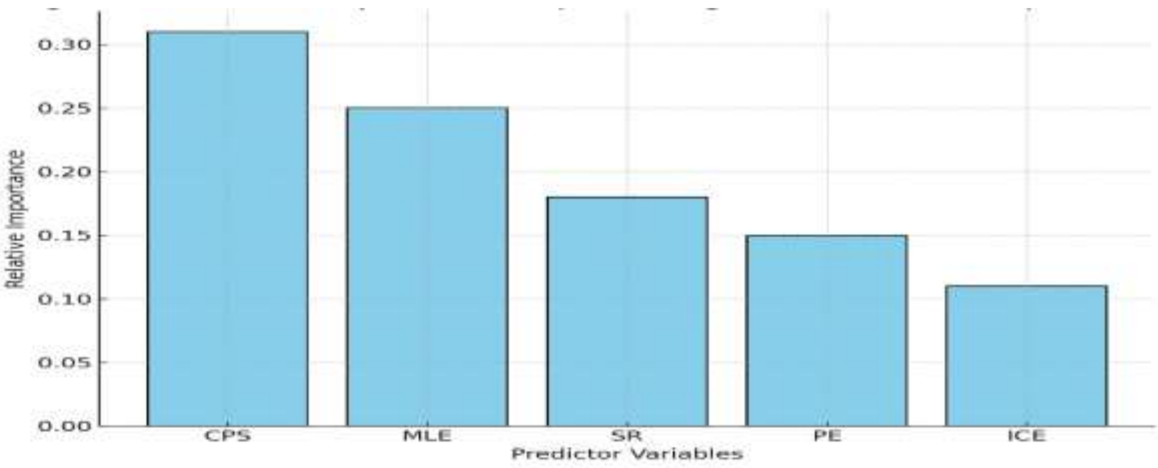

Figure 2. Variable importance in predicting menu innovation performance

The correlation analysis between Sustainability Rating (SR) and Waste Reduction Efficiency (WRE) across all restaurants showed a strong positive relationship ($r = 0.73$, $p < 0.001$), as illustrated in Figure 3. This relationship demonstrates that restaurants that prioritize sustainable sourcing and eco-friendly menu designs also exhibit greater efficiency in reducing food waste and optimizing inventory. The regression line trend in the plot confirms that higher sustainability practices correspond to improved operational outcomes, reinforcing the argument that sustainable innovation leads to both ecological and economic benefits.

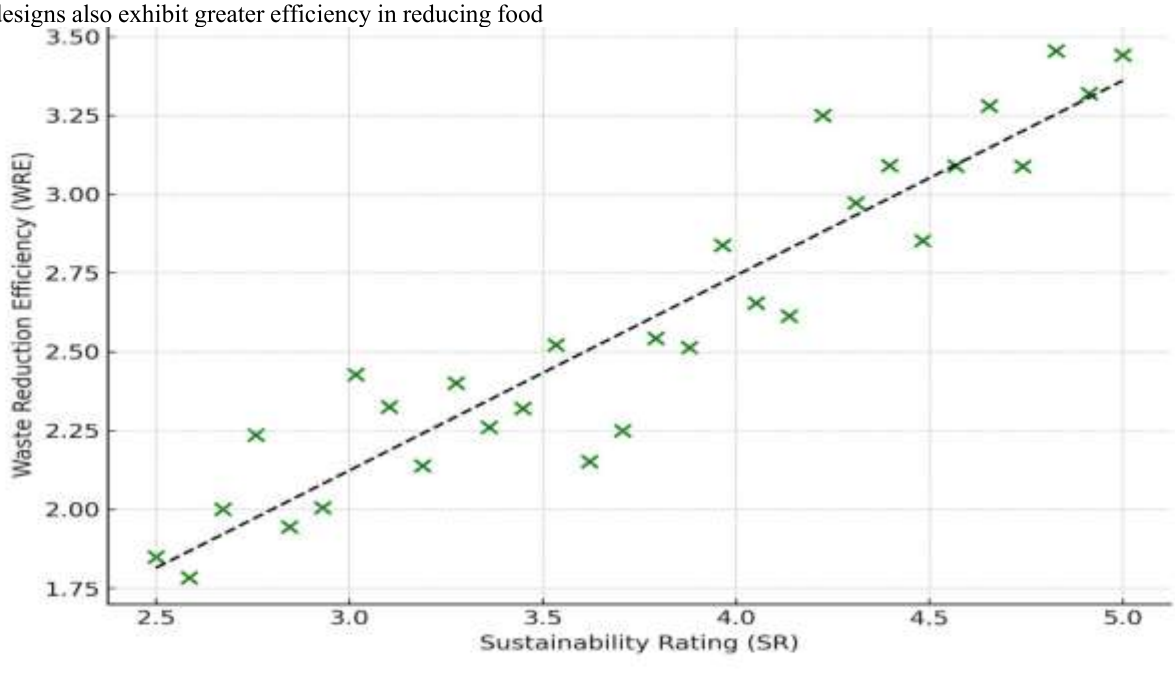

Figure 3. Correlation plot between SR and WRE in restaurants

Discussion

Integrating data analytics into the creative process of menu design

The findings of this study highlight the growing role of data analytics as an essential complement to traditional culinary creativity. As revealed in Table 1, high Consumer Preference Scores (CPS) and Menu Layout

Effectiveness (MLE) demonstrate that customer-centered decision-making enhances both aesthetic and experiential satisfaction. The incorporation of real-time data from POS systems and customer feedback transforms menu development from a static, intuition-based process into a dynamic, evidence-driven system (Szczygłowska, 2021). These results align with previous research suggesting that data-driven creativity improves accuracy in predicting consumer behavior and allows chefs and managers to experiment with menu elements while minimizing financial risk (Varshney et al., 2019). Thus, analytics serves not as a replacement for creativity, but as a structured guide that amplifies its effectiveness in modern restaurant operations.

The importance of consumer-centric design in driving innovation

The regression results (Table 3) and predictive modeling (Figure 2) clearly indicate that Consumer Preference Score (CPS) and Menu Layout Effectiveness (MLE) are the strongest predictors of Menu Innovation Performance (MIP). This supports the concept that restaurant innovation must begin with an understanding of customer psychology, sensory appeal, and perceived value (Dew et al., 2022). The data confirm that menus with engaging descriptions, intuitive layouts, and visual coherence significantly influence customer decision pathways, consistent with theories in consumer cognitive behavior and menu psychology (Fattahi, 2020). These outcomes reinforce that restaurants should prioritize customer data analytics, A/B testing of menu visuals, and sentiment analysis from online reviews to continually adapt their offerings. By aligning menu design with customer expectation, data-driven creativity bridges the gap between perception and performance (Alonso et al., 2018).

Linking sustainability and operational efficiency

The strong positive correlation between Sustainability Rating (SR) and Waste Reduction Efficiency (WRE) (Figure 3) reveals that environmentally responsible practices are not just ethical imperatives but also strategic assets for operational excellence. Restaurants that utilized data to monitor ingredient sourcing, stock rotation, and waste patterns reported higher performance in both cost-efficiency and consumer satisfaction (Fulker et al., 2016). The results suggest that sustainability analytics including tracking food waste, carbon footprint, and energy use should be embedded into menu design frameworks (Majeed & Hwang, 2021). This finding corresponds with global trends in the food service sector emphasizing circular economy principles, where waste minimization and local sourcing enhance both profitability and brand image (Wang et al., 2021).

The multidimensional nature of menu innovation

Factor analysis results (Table 2) identified three key dimensions; Consumer-Centric Design, Cost–Sustainability Integration, and Dynamic Pricing Strategy collectively explaining 74.62% of the variance in menu innovation. This indicates that innovation in menu development is not a single construct but an intersection of aesthetic, operational, and economic components. These dimensions echo the Triple Bottom Line (TBL) framework, emphasizing that successful innovation must integrate social (consumer satisfaction), environmental (sustainability), and financial (cost management) goals (Morabito, 2015). Moreover, the Pricing Strategy component underscores that innovation is effective only when the perceived value aligns with customers' willingness to pay, reinforcing the need for elasticity modeling and demand forecasting in menu pricing (Mondo et al., 2022).

Typology of restaurants and the path to innovation maturity

Cluster analysis results (Figure 1 and Table 4) identified three restaurant typologies Consumer-driven innovators, Operational optimizers, and Traditional cost-focused units. These classifications reflect varying stages of data maturity and innovation adoption. Consumer-driven innovators exhibit the highest performance in both sustainability and consumer engagement, indicating that data utilization and creative flexibility coexist most effectively in this group (Gutierrez-Franco et al., 2021). Operational optimizers balance efficiency and innovation but require stronger consumer insight integration, while Traditional cost-focused units lag due to reliance on outdated pricing and design strategies (Alqahtani et al., 2022). This typology parallels the Diffusion of Innovation Theory (Rogers, 2003), suggesting that early adopters of data-driven systems gain a competitive edge, while late adopters risk losing market adaptability (Tamagusko & Ferreira, 2020).

Implications for managerial practice and policy

From a managerial perspective, these findings offer actionable insights into how restaurant leaders can leverage data for continuous improvement. Data integration should begin at the conceptual stage of menu planning, extending to ingredient procurement, design iteration, and post-launch evaluation (Alrobaie & Krarti, 2022). Predictive analytics tools, such as those used in the present study, allow for accurate forecasting of menu item performance, enabling evidence-based decisions in marketing and resource allocation. Policymakers and industry bodies can also encourage adoption of sustainable analytics platforms through incentives and training programs, particularly for small and medium-sized food enterprises (Wang et al., 2022). This will promote digital transformation while advancing national sustainability goals in the hospitality sector.

Theoretical and conceptual significance

The study extends the theoretical discourse on data-driven innovation and culinary management by empirically validating the role of analytics in menu design (Tang et al., 2018). It bridges multiple theoretical lenses including Resource-Based View (RBV), Consumer Psychology, and Sustainability Innovation Theory to propose a holistic model of data-driven creativity. The results demonstrate that intangible assets such as customer insights, design analytics, and sustainability data form strategic resources that yield competitive advantages (Ren et al., 2014). Thus, this research contributes to emerging scholarship on how big data transforms creative industries, offering a blueprint for integrating quantitative rigor with culinary artistry.

Conclusion

The present study demonstrates that data-driven approaches have redefined the process of menu development, transforming it from a purely creative endeavor into a strategic, evidence-based practice that integrates consumer insights, sustainability, and operational efficiency. By analyzing variables such as Consumer Preference Score (CPS), Menu Layout Effectiveness (MLE), Sustainability Rating (SR), and Menu Engineering Index (MEI), the research establishes that consumer-centric design and sustainable operations are the most influential determinants of menu innovation performance. Predictive analytics and clustering models further revealed how restaurants adopting advanced data practices achieve superior innovation outcomes, aligning profitability with environmental responsibility. The findings affirm that when restaurants systematically employ analytics to guide design, pricing, and sustainability choices, they not only enhance customer satisfaction but also build long-term resilience in a rapidly evolving food service landscape. Ultimately, this study underscores that the future of restaurant innovation lies in the synergy between culinary creativity and data intelligence where informed experimentation drives both competitive advantage and meaningful sustainability.

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