RESEARCH ARTICLE

AI-driven Data Management of Traditional Tunisian Nutritional Dishes: A Cultural Heritage Conservation

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Abstract

The potential loss of traditional Tunisian dishes threatens the sustainability of valuable cultural and nutritional traditions. To help preserve this rich heritage, a conversational AI system has been developed that employs advanced language processing and machine learning techniques to bring Tunisia's culinary traditions to life in a digital space. Multilingual transformer models have been adapted to understand Tunisian dialects and combined with a detailed Food Heritage Knowledge Graph, allowing personalized, interactive access to authentic recipes and the stories behind them. A hybrid dialogue system operated by a chatbot has been implemented to ensure smooth, meaningful conversations that respect cultural sensitivities and build user trust and engagement.Despite challenges such as dialect diversity and limited data, it is demonstrated that modern AI can effectively capture and share complex cultural knowledge. Plans are underway to expand dialect support through federated learning and to improve contextual understanding with smarter memory models. Overall, this project highlights how technology and tradition can be connected through AI, supporting cultural preservation, promoting gastronomic tourism, and encouraging healthier eating habits in Tunisia.

Keywords: cultural heritage preservation, nutritional data systems, natural language processing, interactive platform, food heritage digitization.

1 Introduction

Traditional Tunisian cuisine reflects centuries of several civilizations influences and indigenous improved practices, embodying unique tastes, local nutritional richness, and cultural identity. In the North African, Arabian, and Mediterranean context, Tunisian culture has been continuously enriched, with many gastronomic dishes, couscous being a prime example, recognized at the international level.Yet, many iconic dishes are now endangered due to modernization, globalized eating patterns, and the disruption of oral transmission between generations [1, 2]. Preserving this national culinary heritage is essential not only for

Submitted: 02 September 2025
Accepted: 12 October 2025
Published: 07 December 2025

Vol. 1, **No.** 2, 2025.
10.62762/NGCST.2025.714702

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Citation
Rebai, O., Charni, M., Aribi, H. B., Temessek, M. B., Fattouch, S., & Raboudi, F. (2025). AI-driven Data Management of Traditional Tunisian Nutritional Dishes: A Cultural Heritage Conservation. *Next-Generation Computing Systems and Technologies*, 1(2), 54–61.

cultural diversity but also for sustainable nutrition and food sovereignty [3].

2 Related Work

Digital innovation,particularly cutting-edge computing and artificial intelligence (AI) offers promising tools to safeguard intangible heritages. In recent years, AI-driven cultural preservation systems have demonstrated their capacity to archive, contextualize, and disseminate local knowledge at regional and international scales [4]. This research paper presents a culturally-aware conversational AI system specifically designed to preserve risked Tunisian dishes, facilitate their rediscovery, and promote awareness of their nutritional value through interactive user engagement.

While food heritage documentation often relies on static records, museums, or cookbooks, which are frequently available only as printed sheets or PDFs, these methods inadequately address dynamic community engagement or evolving user needs in the information age. Additionally, some culinary knowledge is shared verbally and lacks any material documentation, making it an immaterial heritage that risks being lost. This highlights the increasing necessity of digitalizing both tangible and intangible food heritage to ensure its preservation and accessibility [5]. In contrast, conversational AI systems, based on advances in natural language understanding (NLU) and human-computer interaction, offer personalized and scalable pathways for users to explore food knowledge intuitively [6, 7]. Their potential is especially relevant for preserving oral traditions and regional dialects, which are essential carriers of culinary knowledge.

Tunisia's rich food traditions are facing challenges because younger generations are changing their eating habits and tastes. As a result, many traditional recipes risk slowly disappearing over time [8]. This situation rises the need for technological tools, especially cutting-edge digitalized means, that can help preserving and bringing these dishes back to life. Traditional meals like Mloukhia, Assidat Zgougou, and Ojja, which used to be common on tables, are now less popular, especially among young people in modern cities [9]. Using AI, chatbots, and interactive platforms that understand Tunisian dialects to better interpret local terms describing meals and recipes, while considering their cultural and emotional backgrounds, can greatly enhance the sharing of accurate knowledge about these at-risk dishes. By emphasizing their nutritional and health benefits, this technological approach can encourage younger generations to rediscover and appreciate them [10].

Renewed interest from younger generations might inspire restaurants and food industry to reintroduce these traditional recipes to their menus, helping to preserve important aspects of Tunisia's culinary heritage. By combining a food heritage database, local dialect language processing, and AI-powered chat systems, this approach bridges traditional food culture with modern computing. It supports cultural preservation while developing AI applications that are inclusive and meaningful to local communities.

3 Methodology

The development of the culturally-aware conversational AI system was structured around a multidisciplinary pipeline combining food ethnography, nutritional science, computational linguistics, and artificial intelligence. The methodology comprised five key phases: (1) data acquisition and knowledge modeling, (2) architecture design, (3) language processing and model training, (4) conversational agent development, and (5) pilot deployment and evaluation.

3.1 Data Acquisition and Knowledge Graph Construction

3.1.1 Ethnographic and Culinary Data Collection

To build a culturally-aware and context-sensitive knowledge base, an ethnographic qualitative survey was conducted in close collaboration with culinary historians, local chefs, anthropologists, and elderly informants across various Tunisian regions. The purpose was to document endangered traditional dishes that are progressively disappearing from everyday culinary practice due to urbanization, modernization, and the erosion of oral food traditions. Data collection focused on emblematic dishes, such as couscous bel Osbane, Metfouna, Chakchouka,and Omek Houria, not only allowed capturing detailed traditional recipes but also reveal regional variants, ingredient sourcing practices (local markets, home gardens, foraging), as well as preparation rituals transmitted through generations. Particular attention was given to the cultural significance of each dish and its role in festive, seasonal, or ceremonial contexts, providing insights into embedded symbolic meanings and social functions. The fieldwork followed participatory approaches and was supported by semi-structured interviews and recipe documentation.

This qualitative study was then codified and analyzed to feed the AI system's ontology layer and natural language processing modules. Integrating such ethnographic depth is crucial for developing AI systems that are not only technically robust but also socially and culturally responsive [11, 12]. This methodology aligns with recent interdisciplinary efforts that merge computational techniques with food heritage preservation [13], and responds to the growing call for ethical, inclusive AI technologies rooted in local knowledge systems [14].

3.1.2 *Nutritional and Functional Composition*

The nutritional profiling of each endangered traditional dish was conducted using a hybrid approach combining data from the Tunisian national food composition tables [15] with targeted laboratory analyses for specific, under-documented ingredients. Additional laboratory analyses were to determine the micronutrient and phytochemical composition, especially for less standardized ingredients such as wild herbs. These analyses help substantiate the functional potential of traditional Tunisian dishes, not only as cultural artifacts but as nutrient-dense food solutions that could address emerging public health concerns such as micronutrient deficiencies and chronic inflammation. The integration of ethnographic context with biochemical data provides a robust basis for valorizing these foods in contemporary dietary frameworks [16].

3.1.3 *Ontology and Semantic Structuring*

Created domain-specific ontology using OWL/RDF to formalize links between ingredients, preparation steps, nutritional values, and cultural tags (e.g., region, occasion, religious relevance). This structured knowledge was embedded into a custom Food Heritage Knowledge Graph (FHKG), ensuring interoperability and scalability.

3.2 System Architecture

The proposed system adopts a modular client-server architecture designed to deliver scalable, culturally-aware interactions for the preservation and dissemination of Tunisian culinary heritage. The architecture comprises five major components, working in synergy to ensure adaptability, personalization, and linguistic sensitivity (see Figure 1).

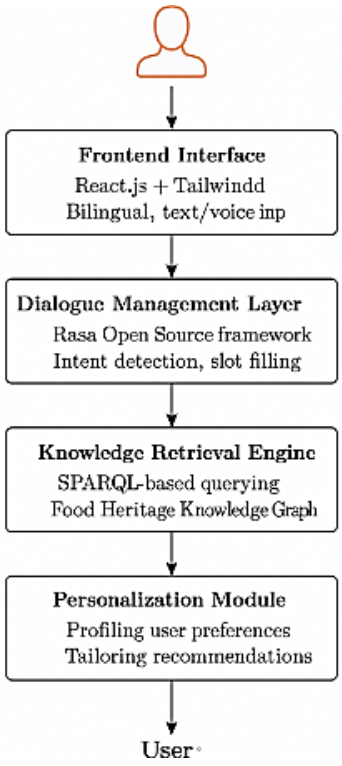

Figure 1. The system architecture diagram.

3.2.1 *Frontend Interface*

The user-facing interface (see Figure 2) is developed using React.js and Tailwind CSS, offering a responsive experience across web and mobile platforms. It supports bilingual interaction in Tunisian Arabic and French (with an English translation in progress) and is equipped with both text- and voice-based input modalities, ensuring inclusivity for diverse user preferences and literacy levels [17].

A customized Rasa Open-Source framework forms the dialogue management backbone, incorporating culturally-contextualized intent recognition and slot-filling strategies. The intent classifiers have been trained on annotated corpora of food-related dialogues in Tunisian dialects, enabling the bot to understand inquiries about dish history, preparation steps, and nutritional value [18].

3.2.2 *Natural Language Processing (NLP) Layer*

The NLP module integrates custom-trained transformer-based models, fine-tuned on a domain-specific corpus comprising culinary blogs, oral histories, and recipe collections. This adaptation addresses the low-resource status of North African dialects and significantly improves entity recognition and sentiment understanding [19].

3.2.3 *Knowledge Retrieval Engine*

A SPARQL-enabled semantic engine interfaces with a structured Food Heritage KnowledgeGraph (FHKG) that encodes dish properties, ingredient networks,

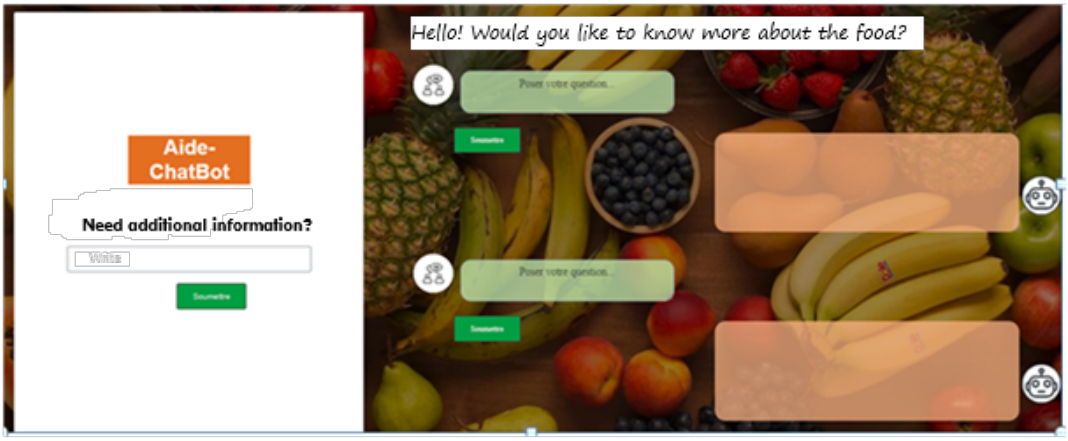

Figure 2. Web interface of the Tunisian Food Composition Database integrated with the AI-powered chatbot, enabling interactive and real-time access to nutritional information.

regional variations, and seasonal availability. This enables dynamic and semantically accurate responses to user queries, ensuring the bot retrieves contextually relevant and culturally valid information [20].

3.2.4 Personalization Module

This module constructs user profiles based on preferences, dietary restrictions, and cultural backgrounds. Using collaborative filtering and content-based recommendation algorithms, the system suggests dishes that align with the user's health goals or traditional practices such, vegetarian variants of Ojja or low-sodium versions of Mloukhia for hypertensive users [21].This modular design not only enhances system scalability and maintainability but also accommodates future extensions such as regional dish detection via image recognition, seasonal menu planning, and cross-cultural culinary comparison tools.

3.3 Natural Language Processing and Model Training

3.3.1 Preprocessing and Augmentation

Given the scarcity of Tunisian Arabic corpora, data augmentation was performed via back-translation, paraphrasing, and synthesis using TTS/STT pipelines.

3.3.2 Model Fine-Tuning

To enhance the system's ability to understand and interact in culturally specific and linguistically complex contexts, we fine-tuned multilingual transformer-based models, specifically XLM-RoBERTa and AraBERT, using a domain-specific corpus comprising transcribed interviews, user queries, and annotated culinary dialogues in Tunisian Arabic. These models were optimized for key natural language understanding (NLU) tasks including intent classification, named entity recognition (NER), and contextual sentiment detection. The fine-tuned XLM-RoBERTa model achieved an intent classification accuracy of 92.3%, while AraBERT demonstrated an F1-score of 88.5% on the NER task, effectively identifying culturally relevant ingredients, dish names, and cooking methods. Additionally, the system was trained to detect conversational signals such as confusion, politeness, and educational engagement, enabling adaptive responses aligned with user emotional tone and learning intent. This NLU adaptation ensures robust performance in recognizing nuanced expressions and diverse dialectal variations, critical for meaningful and personalized interaction within the culinary heritage domain [22].

3.4 Conversational Agent Development

The development of the conversational agent followed a hybrid architecture, combining rule-based and AI-driven components to ensure both cultural sensitivity and contextual flexibility. Rule-based dialogue flows were implemented to handle critical and non-negotiable topics such as religious dietary practices, fasting guidance during Ramadan, and halal compliance, ensuring culturally respectful interaction [23]. Simultaneously, neural natural language understanding (NLU) and generation (NLG) models powered more open-ended conversations, including storytelling about the historical and regional origins of traditional dishes, nutritional education, and user engagement in food-related dialogue [24]. A custom slot-filling mechanism was adapted to handle multi-faceted dishes like couscous, where ingredients, preparation methods, and meanings vary widely across Tunisia's regions [25]. To enhance

personalization and inclusivity, an emotion-aware response module was integrated, enabling the chatbot to adjust its tone, linguistic complexity, and pedagogical style based on the user's profile such as a student, elderly individual, or public by detecting cues from sentiment and intent signals [26].

4 Experiments

4.1 System Performance Evaluation

The proposed system was evaluated in terms of accuracy, efficiency, and adaptability to different types of nutritional queries. The workflow integrates Natural Language Processing (NLP) techniques with a structured nutritional knowledge graph to ensure precise and context-aware responses. To provide greater clarity on the internal mechanism, we added a pseudo-code representation of the query processing pipeline, as illustrated in Figure 3. This representation illustrates the data flow from user input through NLP processing, database retrieval, and the generation of a personalized nutritional response.

```
Algorithm: Personalized Nutritional Query Processing

Input: User query (natural language)
Output: Personalized nutritional response

Begin
   1. Receive user query (text input)
   2. Preprocess text:
         - Tokenization
         - Stop-word removal
         - Lemmatization
   3. Apply NLP model to identify entities:
         - Food items
         - Nutritional terms
         - Health conditions
   4. Retrieve data from knowledge graph/database:
         - Match entities with nutritional database
         - Extract nutrient composition
   5. Generate personalized response:
         - Adapt recommendations to user profile
         - Ensure cultural and dietary relevance
   6. Return final response to user
```

Figure 3. Workflow of the Nutritional Query Processing Pipeline.

The deployed prototype of the conversational AI system was evaluated across multiple technical and user-centered metrics. Key performance indicators (KPIs) are summarized in Table 1.

4.2 Cultural Relevance and Heritage Retention

An important qualitative outcome of this project was the re-engagement of users with endangered traditional Tunisian dishes. Focus groups and post-interaction surveys revealed that:

- 79% of users discovered or re-learned a forgotten dish, such as Kamounia.
- 63% expressed intent to cook or share these dishes within their family or social circles.
- 91% appreciated the cultural storytelling components integrated into the dialogue, especially among younger users (18–30 years old).

This illustrates that the conversational AI not only acted as an informational tool but also as a cultural mediator, stimulating intergenerational transmission of culinary knowledge.

4.3 Technical Contributions to Next-Generation Systems

This framework introduces several innovative advancements to the field of intelligent systems and next-generation computing technologies. First, it demonstrates the successful adaptation and fine-tuning of multilingual transformer models specifically for under-resourced dialects, notably Tunisian, thereby addressing a critical gap in natural language processing (NLP) for North African contexts and low-resource languages [25]. Second, the development of the Food Heritage Knowledge Graph (FHKG) represents a pioneering semantic database that intricately links nutritional information, cultural narratives, and historical contexts of traditional foods in a structured, machine-readable format, facilitating dynamic and context-aware information retrieval. Third, the system employs a hybrid dialogue management approach that blends rule-based, ethics-sensitive conversational flows essential for handling culturally and religiously sensitive topics with AI-driven natural language generation, ensuring both cultural accuracy and conversational fluidity [23]. Lastly, the integration of a personalized interaction engine leverages user profiling to tailor recommendations according to individual dietary needs, cultural backgrounds, and preferences, thereby enhancing user trust and engagement [25]. Together, these components lay a robust technical foundation for culturally-sensitive conversational AI systems that are scalable and adaptable to diverse regions and heritage domains, marking a significant step forward in inclusive and context-aware AI applications.

4.4 Challenges

Despite achieving promising initial results, the project faced several noteworthy challenges inherent to working with low-resource, culturally rich linguistic contexts. First, the substantial dialectal diversity within Tunisian Arabic marked by significant regional

Table 1. Performance metrics of the conversational AI system.

Metric	Value	Interpretation
NLU Intent Classification Accuracy	92.3%	High accuracy in identifying user intent
Named Entity Recognition (NER) F1-score	88.5%	Effective extraction of cultural and nutritional entities
Dialogue Completion Rate	86.2%	Most users successfully completed food-related queries
Average Dialogue Turns	5.8	Sustained interaction indicating user engagement
Knowledge Graph Query Response Time	320 ms avg	Fast information retrieval
User Satisfaction (SUS Score)	84.7 / 100	High usability and user-friendliness

lexical, phonological, and syntactic variations adversely impacted early natural language processing (NLP) model performance, highlighting the need for federated or multi-dialect training strategies to better encompass this linguistic heterogeneity [22–24]. Second, the scarcity of annotated corpora specific to Tunisian culinary discourse necessitated extensive manual annotation efforts and the application of data augmentation techniques to enhance model robustness; however, scaling such efforts sustainably will require community-driven, participatory annotation frameworks that engage native speakers and domain experts alike [27]. Addressing these challenges is pivotal for improving the system's robustness, scalability, and cultural adaptability, especially within low-resource and highly diverse computing environments, and will inform future developments in AI for cultural heritage preservation.

5 Conclusion

This work presents a novel, culturally-aware conversational AI system that bridges advanced natural language processing techniques with the preservation and dissemination of Tunisia's endangered culinary heritage. By successfully fine-tuning multilingual transformer models for under-resourced Tunisian dialects and integrating a semantically rich Food Heritage Knowledge Graph, the system demonstrates the feasibility and value of next-generation computing technologies in addressing complex, culturally embedded knowledge domains. The hybrid dialogue management approach ensures both ethical sensitivity and conversational fluidity, while personalized interaction enhances user engagement and trust. Despite challenges related to dialect diversity, limited annotated data, and contextual ambiguity, this project lays a scalable foundation for AI-driven cultural heritage applications in linguistically and socially diverse settings. Future work will focus on expanding dialectal coverage via federated learning, enriching contextual understanding through advanced memory models, and extending the system to other heritage domains and regions. Overall, this research contributes significant technical and societal insights toward developing intelligent systems that are not only computationally robust but also deeply attuned to cultural nuances.

Data Availability Statement

Data will be made available on request.

Funding

This work was partly supported by the PRIMA Programme, funded by the European Union, under Grant Agreement No. 2132 (Project: PROMEDLIFE).

Conflicts of Interest

The authors declare no conflicts of interest.

Ethical Approval and Consent to Participate

Not applicable.

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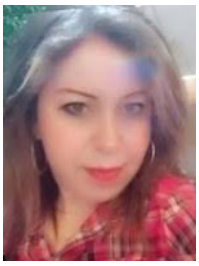

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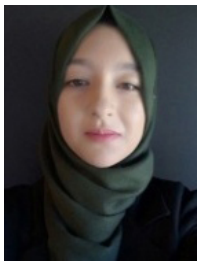

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