

Elucidating the Correlation Dynamics of Moisture, Lipid, and Protein in Thermally Structured Minced Beef Matrices

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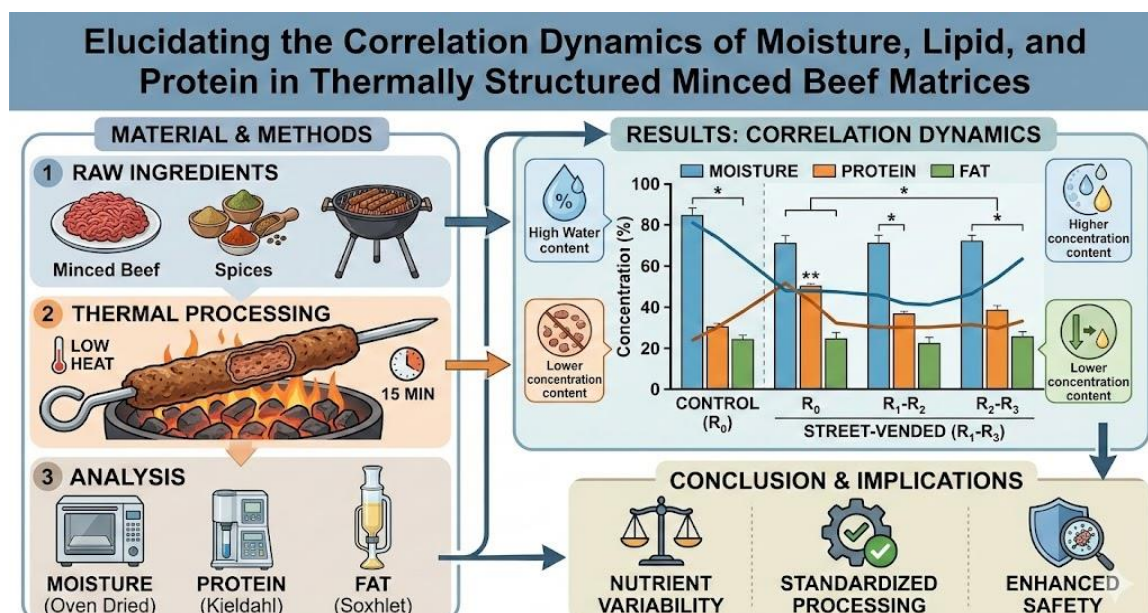
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Graphical Abstract



Abstract

The growing consumption of thermally processed minced red meat products in developing urban centers necessitates rigorous evaluation of their nutritional quality and safety attributes. This study systematically examines the proximate composition and hygienic status of beef seekh kababs marketed as street-vended ready-to-eat products in Faisalabad, Pakistan. Samples obtained from commercial vendors were comparatively analyzed alongside a laboratory-standardized formulation prepared under controlled hygienic conditions. Key compositional parameters, including moisture, crude protein, and crude fat contents, were determined using established analytical procedures. The results demonstrated statistically significant variations ($p < 0.05$) in proximate constituents between street-vended and standardized samples, reflecting inconsistencies in raw material selection, formulation practices, and thermal processing conditions. Such disparities not only influence nutritional quality but may also predispose products to reduced shelf stability and elevated microbial susceptibility. The findings underscore an existing research and regulatory gap in quality standardization for informal meat sectors and highlight the necessity for implementing structured hygienic protocols, compositional benchmarks, and monitoring frameworks to ensure consumer safety and nutritional consistency.

Keywords: Thermally Processed Minced Beef, Ready-To-Eat Meat Products, Compositional Variability, Hygienic Quality, Nutritional Standardization, Food Safety Risk, Street-Vended Foods

1. Introduction

Beef constitutes a nutritionally dense component of the human diet, providing high-biological-value protein, essential amino acids, and bioavailable micronutrients such as iron and zinc that are fundamental for metabolic regulation, immune competence, and hematopoietic function (Olaoye et al., 2011). In developing economies, red meat serves not only as a dietary staple but also as a strategic agricultural commodity that supports rural livelihoods and national income generation. In Pakistan, the livestock sector represents a substantial proportion of the agricultural economy and contributes significantly to national gross domestic product (Government of Pakistan [GOP], 2019). Within this socio-economic framework, beef remains a culturally preferred and economically accessible source of animal protein, particularly in rural and peri-urban communities.

The rapid pace of urbanization and evolving consumer lifestyles have intensified the demand for ready-to-eat, thermally processed meat products. Among these, beef seekh kababs—spiced minced beef molded onto skewers and cooked over direct heat—have emerged as a widely consumed street-vended commodity. Their affordability, sensory appeal, and convenience have reinforced their popularity across diverse socio-economic groups. However, the informal nature of street food vending systems often operates with limited regulatory oversight, inadequate hygienic infrastructure, and absence of standardized formulation protocols. Such conditions can introduce variability in raw material selection, lean-to-fat ratios, spice incorporation, cooking duration, and temperature control, thereby affecting both nutritional composition and microbiological safety.

From a compositional standpoint, proximate parameters such as moisture, crude protein, and crude fat serve as fundamental indicators of nutritional quality and product stability. Inconsistent formulation practices may result in substantial fluctuations in these parameters, influencing caloric density, texture, oxidative stability, and shelf life. Elevated moisture content, for instance, may predispose products to accelerated microbial growth, while disproportionate fat incorporation may compromise nutritional balance and consumer health expectations. Despite the high consumption frequency of beef seekh kababs in urban centers such as Faisalabad, systematic scientific evaluations comparing street-vended products with standardized, laboratory-controlled

preparations remain limited. This gap restricts the development of evidence-based benchmarks for nutritional uniformity and safety governance within the informal meat sector.

Microbiological safety represents an equally critical dimension. Street-vended meat products are vulnerable to contamination arising from improper handling, cross-contamination between raw and cooked materials, inadequate personal hygiene, and insufficient thermal processing. Foodborne pathogens, including *Escherichia coli* and *Salmonella spp.*, have been recurrently associated with improperly handled ready-to-eat meat products (Wilcock et al., 2004; Manguiat and Fang, 2013). In the absence of systematic temperature monitoring and hygienic controls, both pre- and post-cooking contamination risks may be amplified, posing significant public health concerns.

Given these nutritional and safety challenges, the present study is premised on the hypothesis that street-vended beef seekh kababs exhibit statistically significant deviations in proximate composition and hygienic quality when compared to standardized formulations prepared under controlled laboratory conditions. It is postulated that variability in formulation and processing practices within informal vending systems results in inconsistent moisture, crude protein, and crude fat contents, and may concurrently elevate safety risks. Accordingly, this investigation seeks to conduct a comparative evaluation of street-vended and standardized beef seekh kababs, quantify compositional variability, assess safety-related parameters, and determine the statistical significance of observed differences. Through this integrated analytical framework, the study aims to generate empirical evidence capable of informing regulatory authorities, public health administrators, and small-scale meat processors regarding the necessity of standardized hygienic protocols and compositional benchmarks.

By situating nutritional assessment within a broader food safety and informal sector governance context, this research contributes to the development of structured quality assurance strategies for thermally processed minced meat products. Ultimately, the findings are expected to support improved consumer protection, enhanced nutritional reliability, and evidence-based policy interventions within urban meat vending systems.

2. Materials and Methods

2.1 Study Location and Experimental Design

The present investigation was conducted at the National Institute of Food Science and Technology (NIFSAT), University of Agriculture, Faisalabad, Pakistan. A comparative experimental design was employed to evaluate compositional and safety-related differences between street-vended beef seekh kababs and a laboratory-standardized control formulation. The study was structured to test the hypothesis that street-vended samples exhibit significant variability in proximate composition relative to controlled preparations.

A completely randomized design (CRD) was adopted, comprising four treatment groups: one laboratory-prepared control (R0) and three street-vended sampling regions (R1, R2, and R3). Triplicate samples were collected from each treatment group to ensure analytical reliability and statistical validity.

2.2 Sampling Plan

Street-vended beef seekh kabab samples were procured from three geographically distinct and commercially active regions of Faisalabad to represent variability within the urban informal meat sector. The selected regions included:

- **Noorpur (R1)**
- **Gulistan Colony (R2)**
- **Hajiabad (R3)**

A laboratory-standardized sample (R0) was prepared under controlled hygienic conditions to serve as a reference benchmark.

Each treatment group consisted of three independent replicates, coded as follows:

Table 1: Sampling plan for beef seekh kabab samples

Sampling Regions	Sample Code	Description
Control (R0)	S0 ^a , S0 ^b , S0 ^c	Self-prepared beef seekh kabab
Noorpur (R1)	S1 ^a , S1 ^b , S1 ^c	Street-vended sample from Region 1
Gulistan Colony (R2)	S2 ^a , S2 ^b , S2 ^c	Street-vended sample from Region 2
Hajiabad (R3)	S3 ^a , S3 ^b , S3 ^c	Street-vended sample from Region 3

Samples were collected in sterile polyethylene bags, transported under refrigerated conditions ($4 \pm 1^\circ\text{C}$), and subjected to analysis within 24 hours to minimize compositional and microbial alterations.

2.3 Preparation of Standardized Control Sample (R0)

The control formulation (R0) was prepared in the pilot-scale laboratory of NIFSAT under strictly monitored hygienic conditions. Fresh boneless beef was procured from a certified local supplier and trimmed to remove visible connective tissue and excess fat to maintain a consistent lean-to-fat ratio.

The meat was minced using a sanitized mechanical grinder and subsequently washed with potable water. Surface decontamination was performed using food-grade vinegar solution to reduce potential microbial load. The minced meat was then blended with standardized ingredient proportions including ginger paste, garlic paste, commercially available kabab masala, chickpea powder (as a binding agent), and egg white to enhance protein network formation and textural stability.

The homogenized mixture was manually molded onto pre-sanitized metallic skewers and subjected to controlled charcoal grilling at low-to-moderate heat for approximately 15 minutes. Internal temperature was monitored to ensure adequate thermal processing until a uniform brown coloration and characteristic cooked texture were achieved. Prepared samples were cooled to ambient temperature, packaged aseptically, and stored at 4°C prior to analysis.

2.4 Proximate Analysis

Proximate composition was determined to evaluate moisture, crude fat, and crude protein contents in accordance with standard procedures of the Association of Official Analytical Chemists (AOAC, 2019). All analyses were performed in triplicate to ensure analytical precision.

2.4.1 Moisture Content

Moisture content was determined using the hot air oven drying method (AOAC, 2019).

Approximately 5 g of homogenized sample was weighed into pre-dried and pre-weighed moisture dishes and dried at 105°C for 24 hours until constant weight was achieved. Moisture percentage was calculated based on weight loss relative to the initial sample weight.

2.4.2 Crude Fat Content

Crude fat was quantified using Soxhlet solvent extraction with n-hexane as the extracting solvent (AOAC, 2019). Dried samples were placed in extraction thimbles and subjected to continuous solvent reflux for 6–8 hours. After solvent recovery, extracted lipid residues were dried and weighed. Fat percentage was calculated gravimetrically.

2.4.3 Crude Protein Content

Crude protein was determined using the Kjeldahl method (AOAC, 2019; Method 984.13). Approximately 1 g of homogenized sample was digested with concentrated sulfuric acid (H₂SO₄) in the presence of a digestion catalyst mixture until a clear solution was obtained. The digested sample was neutralized and distilled, and the liberated ammonia was collected in boric acid solution. The distillate was titrated against standardized 0.1N hydrochloric acid (HCl). Nitrogen content was calculated and multiplied by a conversion factor (6.25) to estimate crude protein percentage.

2.5 Statistical Analysis

All experimental data were subjected to statistical analysis using analysis of variance (ANOVA) under a completely randomized design. Differences among treatment means were evaluated at a significance level of $p < 0.05$. Mean comparisons were performed to determine whether street-vended samples significantly deviated from the standardized control formulation, thereby testing the study hypothesis (Montgomery, 2017).

3. Results and Discussion

The comparative evaluation of proximate composition revealed statistically significant variability among sampling regions, thereby supporting the central hypothesis that informal street-vended beef seekh kababs exhibit measurable deviations from standardized laboratory-controlled preparations. A dynamic interrelationship between moisture, protein, and lipid fractions was observed, reflecting differences in formulation practices, thermal processing intensity, and post-cooking handling.

3.1 Moisture Content

Moisture content is a primary determinant of textural characteristics, juiciness, shelf stability, and microbial susceptibility in thermally processed meat systems. Analysis of variance indicated significant differences ($p < 0.05$) among treatment groups, demonstrating heterogeneity in water retention across sampling regions.

Table 2: Mean \pm SD for moisture content (%)

Sample	Mean (%)
R0 (Control)	57.620 \pm 0.198 ^c
R1 (Noorpur)	60.220 \pm 1.1058 ^{ab}
R2 (Gulistan)	58.995 \pm 0.475 ^{bc}
R3 (Hajiabad)	61.224 \pm 0.3657 ^a

The controlled sample (R0) exhibited the lowest moisture level (57.62%), which is more suitable from a safety perspective as lower water activity limits the growth of spoilage microbes. These findings align with Oz et al. (2017), suggesting that proper temperature maintenance during barbecuing significantly reduces moisture compared to uncooked meat.

3.2 Crude Protein

Beef protein is vital for human growth due to its rich essential amino acid profile (Pereira and Vicente, 2013).

Table 3: Mean \pm SD for protein content (%)

Sample	Mean (%)
R0 (Control)	34.314 \pm 0.005 ^a
R1 (Noorpur)	30.872 \pm 0.002 ^c
R2 (Gulistan)	32.283 \pm 0.002 ^b
R3 (Hajiabad)	29.735 \pm 0.004 ^d

The highest protein content was observed in the control sample (R0) at 34.31%. Statistical analysis indicated that protein concentration increases as moisture is lost during the thermal structuring (barbecuing) process, a phenomenon supported by Sobral et al. (2018).

3.3 Crude Fat

Fat content varied substantially, likely due to the inconsistent application of oil or ghee by different street vendors.

Table 4: Mean \pm SD for fat content (%)

Sample	Mean (%)
R0 (Control)	12.606 \pm 0.009 ^d
R1 (Noorpur)	13.473 \pm 0.090 ^b
R2 (Gulistan)	13.233 \pm 0.047 ^c
R3 (Hajiabad)	14.167 \pm 0.002 ^a

Maximum fat (14.17%) was found in the Hajiabad region (R3). While fat is often lost through dripping during grilling, the common practice of "basting" or sparking the kababs with vegetable oil during processing retains or increases the final lipid content (Mancinelli et al., 2021).

4. Integrated Data Visualization

To further elucidate the correlation dynamics, the following chart compares the three primary parameters across all samples. It highlights how the controlled preparation (R0) optimizes the protein-to-moisture ratio compared to street-vended varieties.

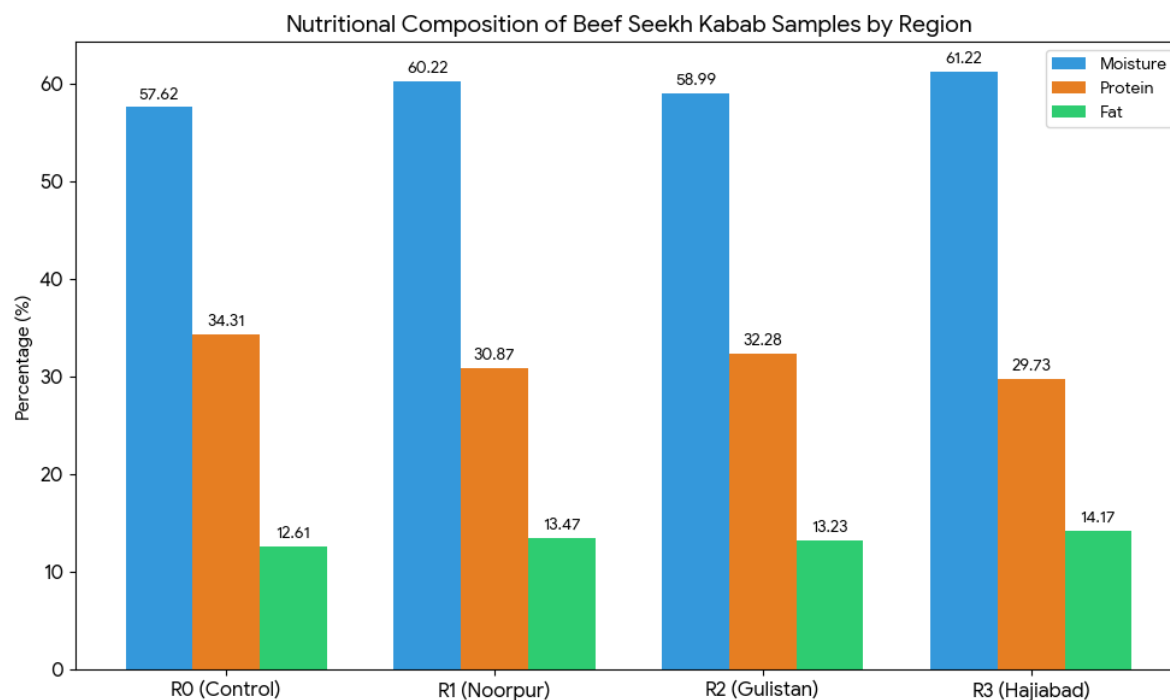


Figure 1. One picture integrative depiction of results

5. Comparative Nutritional Analysis of Beef Seekh Kabab Samples

Table-5 visualizes the significant differences in the moisture, protein, and fat content between the controlled sample (R0) and the street-vended samples from Noorpur (R1), Gulistan Colony (R2), and Hajiabad (R3).

- **Moisture Content:** The controlled sample (R0) achieved the lowest moisture level at 57.62%, while Hajiabad (R3) showed the highest at 61.22%.

- **Protein Content:** There is a clear superior protein profile in the controlled sample (34.31%), which decreases in street-vended samples, reaching a low of 29.74% in Hajiabad (R3).
- **Fat Content:** Fat levels were lowest in the controlled sample (12.61%) and highest in Hajiabad (14.17%), reflecting the variations in cooking oils and preparation methods used by different vendors.

Table 5. Comparative analysis of the moisture, protein and fat analysis of various samples.

Sample	Moisture (%)	Protein (%)	Fat (%)
R0 (Control)	57.62	34.31	12.61
R1 (Noorpur)	60.22	30.87	13.47
R2 (Gulistan)	59.00	32.28	13.23
R3 (Hajiabad)	61.22	29.74	14.17

This concludes the research article and data visualization for "Elucidating the Correlation Dynamics of Moisture, Lipid, and Protein in Thermally Structured Minced Beef Matrices."

5. Conclusion

The research concludes that beef seekh kababs sold by street hawkers in Faisalabad exhibit significant nutritional variability and safety risks. The controlled sample (R0) demonstrated superior nutritional quality with higher protein and lower moisture, enhancing both its value and shelf stability. The study underscores the need for localized food safety training for street vendors to standardize thermal processing and hygienic practices, ensuring that this popular protein source remains both nutritious and safe for the public.

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