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RESEARCH ARTICLE

VARIABILITY IN THE NUTRITIONAL DENSITY OF MAIZE-BASED MEALS IN THE CITIES OF ABECHE, MOUNDOU AND SARH IN CHAD

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Abstract

In Chad, the nutritional transition is accompanied by a double burden: the persistence of undernutrition and the emergence of metabolic diseases. Maize is one of the most consumed staple foods, mainly in the form of a ball (a local preparation made from cornmeal and hot water, stirred until a compact dough is obtained) accompanied by sauces. However, the nutritional density of this fundamental meal has never been compared between different Chadian cities, despite contrasting agroecological and culinary contexts. The aim of this study was to compare the macronutrient composition(proteins, lipids, carbohydrates, moisture) of the « maize ball + sauce » meal in three Chadian cities with distinct profiles : Abéché (eastern Sahelian), Moundou (southwest ern agricultural) and Sarh (southern riverside). A food survey was conducted among 200 households per city. Standardized samples of maize ball and associated sauces were collected and analyzed in the laboratory using Kjeldahl (proteins), Soxhlet (lipids), Bertrand (carboh ydrates) and desiccation (moisture) methods. The results show that nutritional density varies significantly between the three cities. In Abéc hé, okra-meat sauce had the highest protein (3.79%) and lipid (5.55%) content. In Moundou and Sarh, fish-based sauces were significantly lower in protein (3.45% and 3.12%) and lipids (2.89% and 2.76%), with higher moisture content (>81%). The estimated energy value of the complete meal was 235 kcal/serving in Abéché, compared to 215 kcal in Moundou and 200 kcal in Sarh. The same basic meal thus presents contrasting nutritional profiles depending on the city, with a risk of protein-energy deficiency more pronounced in Sarh. These data can guide contextualized nutritional recommendations.

Introduction:-

Food is one of the major determinants of population health, particularly in low- and middle-income countries where food security remains precarious **(1)**. In Chad, a Sahelian country in Central Africa, the nutritional situation is

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marked by a double burden : on the one hand, the persistence of chronic undernutrition affecting approximately 30% of children under five **(2)**, and on the other hand, the progressive emergence of metabolic diseases such as type 2 diabetes and obesity, particularly in urban areas **(3)**. This nutritional transition largely results from the change in traditional dietary habits, often replaced by processed foods that are high in energy but low in essential nutrients.
In this context, maize (Zea mays) occupies a central place in the Chadian diet. This cereal, widely cultivated and available throughout the country, is consumed daily by a majority of households in the form of a "ball," a thick paste obtained by cooking maize flour in water – accompanied by various sauces (4). The nature of the sauce, its ingredients (meat, fish, leafy vegetables, peanuts), and its method of preparation vary considerably from one region to another, reflecting local agro-ecological, cultural, and economic specificities.

The city of Abéché, located in the Sahelian province of Ouaddaï, is characterized by a strong nomadic influence, frequent consumption of dried meat (charmoute), and the widespread use of butane gas for cooking (88% of households) **(5)**. In contrast, the city of Moundou, in the agricultural province of Logone Occidental, benefits from a greater diversity of leafy vegetables (cassava, beans, spinach) and primarily uses charcoal (67%). As for the city of Sarh, located in the river province of Moyen-Chari, it is distinguished by its privileged access to smoked fish and a marked dependence on charcoal (81%). These differences in context are likely to influence the nutritional composition of the meals consumed, and in particular their macronutrient density.

Despite the importance of maize in the daily diet of Chadians, no study to date has systematically compared the nutritional density of a "maize ball + sauce" meal across different cities in the country. This scientific gap represents a major obstacle to developing contextualized nutritional recommendations adapted to local realities and the specific needs of the population. Thus, the central problem of this research can be formulated as follows: to what extent does the nutritional density of the maize-based meal consumed in the cities of Abéché, Moundou and Sarh vary according to local culinary practices and available ingredients? We formulate the following general hypothesis: the nutritional density of the "corn ball + sauce" meal varies significantly between Abéché, Moundou and Sarh, with meals consumed in Abéché being richer in protein and lipids due to the use of meat, while those in Moundou and Sarh have a lower density, potentially insufficient to cover the nutritional needs of vulnerable groups.

The overall objective of this study is to compare the macronutrient composition of the "corn ball + sauce" meal in the three cities. The specific objectives are :
(1) :determine the protein, fat, carbohydrate, and moisture content of the corn ball in each city ;
(2) : analyze the composition of the associated sauces ;
(3) : estimate the energy density of the complete meal ;
(4) : identify any potential nutritional imbalances.

The importance of this topic lies in its contribution to a better understanding of local nutritional realities, essential for guiding public health policies, nutrition education programs, and malnutrition prevention strategies in Chad. By providing objective data on the quality of daily meals, this study aims to fill a scientific gap and offer policymakers tools tailored to the specific characteristics of each region.

Material and Methods:-

Study sites:-
The study was conducted in three Chadian cities with distinct characteristics. Abéché (Eastern Sahelian) is characterized by a semi-arid climate, high consumption of dried meat (charmoute), and predominantly butane gas cooking (88% of households). Moundou (Southwestern Sudanian) benefits from abundant rainfall, a wide variety of leafy vegetables, and primarily uses charcoal (67%). Sarh (Southern riverine), located near the Chari River, is distinguished by its easy access to smoked fish and a high reliance on charcoal (81%).

Dietary survey and meal selection:-
A cross-sectional food survey was conducted between September and October 2023 with 200 households per city, for a total of 600 households. Households were selected by simple random probability sampling, stratified by neighborhood, in the seven districts of each city. A semi-structured questionnaire, administered face-to-face by trained interviewers, collected information on weekly eating habits, frequency of consumption of different dishes, ingredients used, preparation methods, energy sources for cooking, and the socio-demographic characteristics of the respondents.

Sample preparation and collection:-
The food samples were prepared according to traditional local recipes in collaboration with experienced homemakers from each city to ensure the representativeness and authenticity of the dishes. The ingredients (corn, okra, meat, fish, and seasonings) were purchased from local markets in the three cities.

For each type of meal, three independent samples were prepared on different days to account for potential variability. The corn ball was made by cooking 250g of cornmeal in 500 mL of water, stirring constantly until a smooth paste was formed. The sauces were prepared according to the following protocols

- Okra sauce with meat (Abéché): 200g of fresh cut okra, 150g of beef, onions, tomatoes, peanut oil, salt and spices, cooked for 45 minutes.
- Okra sauce with fish (Moundou and Sarh): 200g of fresh okra cut up, 100g of smoked fish (or 150g of fresh fish in Sarh), onions, tomatoes, peanut oil, salt and spices, cooked for 40 minutes.

After preparation, each sample (ball and sauce separately) was homogenized, packaged in airtight glass containers, labeled, and immediately stored at -20°C before transport to the laboratory in a maintained cold chain.

Biochemical analyses:-
The analyses were carried out at the Quality Control and Analysis Laboratory (CECOQDA) in N'Djamena. Each analysis was performed in triplicate per sample, and the results are expressed as a percentage of fresh weight (%, mean ± standard deviation). Total protein content was determined by the Kjeldahl method, standardized according to the protocols of the Association of Official Analytical Chemists (AOAC, method 984.13). The method includes three steps: (1) mineralization of the sample with concentrated sulfuric acid in the presence of a catalyst (copper sulfate and potassium sulfate) at 420°C for 2 hours and 45 minutes; (2) distillation of ammonia after alkalization with sodium hydroxide; (3) titration with a 0.1 N hydrochloric acid solution in the presence of colored indicators (bromocresol green and methyl red).The nitrogen content was multiplied by the standard conversion factor of 6.25 to obtain the protein content. The total lipid content was determined by the Soxhlet extraction method (AOAC, method 920.39). Approximately 5 g of dehydrated sample were placed in a cellulose cartridge and subjected to continuous extraction with petroleum ether (boiling point 40–60°C) for 6 hours. After evaporation of the solvent, the lipid residue was weighed by gravimetric difference.

Total carbohydrates were determined by the Bertrand method (potassium permanganate redox method). Polysaccharides were hydrolyzed by refluxing in acidic medium (2N HCl) for 2.5 hours. The released reducing sugars were quantified by copper reduction in Fehling's solution, followed by titration with a standardized 0.02 N $KMnO_4$ solution. Carbohydrate content was calculated by reference to a glucose calibration curve. Water content was measured by oven drying according to AOAC standards (method 925.10).For the balls, approximately 5g of sample were placed in an oven at 130-133°C for 3 hours. For the sauces, 2-3g of sample were dried at 105°C for 24 hours. The mass loss after drying allowed for the calculation of the moisture content.

Statistical analysis:-
The data were entered and processed using the Statistical Package for the Social Sciences (SPSS, version 25.0, IBM Corp., Armonk, NY, USA). The results were expressed as means ± standard deviations (m ± SD) for each parameter and each city.The normality of the distributions was verified using the Shapiro-Wilk test. The comparison of means between the three cities was performed using a one-way analysis of variance (ANOVA) followed by Tukey's post-hoc test for multiple comparisons when the conditions of normality and homogeneity of variances (Levene's test) were met. Otherwise, the non-parametric Kruskal-Wallis test was used. The significance level was set at $p < 0.05$.

The energy density of the complete meal (ball + sauce) was estimated by applying Atwater's conversion coefficients: 4 kcal/g for protein, 4 kcal/g for carbohydrate, and 9 kcal/g for fat.

Results:-
The results presented in this section describe the nutritional composition of cornmeal samples and associated sauces collected in the three study cities (Abéché, Moundou, and Sarh). For each parameter, means and standard deviations are reported, and significant differences between cities are indicated.

Nutritional composition of corn kernels:-

Table 1 presents the protein, carbohydrate, and moisture content of the corn ball in the three cities. The fat content of the corn ball was not measured because it is considered negligible (less than 0.5% fat), as no oil was added to the preparation.

Table 1 : Nutritional composition of maize balls in Abéché, Moundou and Sarh (%, fresh weight, mean ± standard deviation, n=3 per city)

Parameters	Abéché (n=3)	Moundou (n=3)	Sarh (n=3)	p (ANOVA)
Protéin (%)	2,64 ± 0,12	2,71 ± 0,09	2,58 ± 0,11	0,324
Carbohydrate (%)	3,75 ± 0,05^b^	4,10 ± 0,08^a^	3,68 ± 0,06^b^	< 0,001
Moisture (%)	32,03 ± 0,41	31,52 ± 0,38	32,18 ± 0,44	0,157

Source : 2023survey

« Values in the same row with different letters (a, b) indicate a significant difference in Tukey's post-hoc test ($p < 0.05$».

Statistical analysis reveals that the protein content of the cornmeal balls did not differ significantly between the three cities ($p = 0.324$), with values ranging from 2.58% to 2.71%. Similarly, the moisture content did not show significant variation ($p = 0.157$), remaining around 31.5% to 32.2%. In contrast, the carbohydrate content varied significantly between cities ($p < 0.001$). The cornmeal balls from Moundou had the highest carbohydrate concentration (4.10%), significantly higher than those from Abéché (3.75%) and Sarh (3.68%). No significant difference was observed between Abéché and Sarh for this parameter.

Nutritional Composition of Associated Sauces:-

Table 2 presents the nutritional composition of the sauces consumed with cornmeal balls in the three cities. It should be noted that the sauce from Abéché is prepared with fresh meat, while those from Moundou and Sarh are made with smoked fish.

Table 2: Nutritional composition of sauces associated with cornmeal balls in Abéché, Moundou and Sarh (%, fresh weight, mean ± standard deviation, n=3 per city)

Parameters	Abéché (Okra Sauce + meat)	Moundou (Okra Sauce + fish)	Sarh (Okra Sauce + fish)	p (ANOVA)
Protéin (%)	3,79 ± 0,15^a^	3,45 ± 0,12^b^	3,12 ± 0,10^c^	< 0,001
Lipid (%)	5,55 ± 0,09^a^	2,89 ± 0,11^b^	2,76 ± 0,13^b^	< 0,001
Carbohydrates (%)	3,05 ± 0,02	3,15 ± 0,03	3,08 ± 0,02	0,089
Moisture (%)	77,84 ± 0,52^c^	81,23 ± 0,61^b^	82,45 ± 0,58^a^	< 0,001

Source : 2023survey

Values in the same row labeled with different letters (a, b, c) indicate a significant difference in Tukey's post-hoc test ($p < 0.05$). Protein analysis reveals a clear hierarchy among the three cities ($p < 0.001$). The sauce from Abéché, containing fresh meat, has the highest protein content (3.79%), followed by the sauce from Moundou (3.45%) and then that from Sarh (3.12%). All differences are statistically significant. For lipids, the same gradient is observed. The Abéché sauce has a significantly higher fat content (5.55%) than the Moundou (2.89%) and Sarh (2.76%) sauces, the latter two not differing from each other ($p > 0.05$).

The carbohydrate content of the sauces did not differ significantly between the three cities ($p = 0.089$), with values ranging from 3.05% to 3.15%. The carbohydrates came primarily from the okra, onions, and tomatoes used in the preparation. Moisture content, however, showed highly significant differences ($p < 0.001$). The sauce from Sarh was the most watery (82.45%), followed by that from Moundou (81.23%), and then that from Abéché (77.84%). This variability reflects distinct cooking practices: the sauce from Abéché is generally more concentrated (less water added, longer cooking time), while the sauces from Moundou and Sarh are more diluted.

Estimated Energy Density of a Complete Meal:-

Based on nutritional composition data, the energy density of a complete meal (corn ball + sauce) was estimated for a standard portion. The portion was defined as the equivalent of 250g of corn ball (fresh weight) combined with 150g of sauce, corresponding to the average quantities consumed by an adult during a main meal in Abéché, Moundou, and Sarh.

Table 3 presents the macronutrient intake and estimated energy value for a standard serving in each city.

Table 3: Estimated nutritional intake for a standard serving of the "corn ball + sauce" meal (250g corn ball + 150g sauce)

Paramètre	Abéché	Moundou	Sarh
Ball mass (g)	250	250	250
Sauce mass (g)	150	150	150
Total Protein (g)	6,39	6,18	5,62
Total lipids (g)	8,33	4,34	4,14
Total carbohydrates (g)	34,58	36,98	34,52
Energy value (kcal)	235,4	215,0	200,3

Source : 2023survey

Figure 1 illustrates the relative contribution of different macronutrients to the total energy intake of the meal in each city.

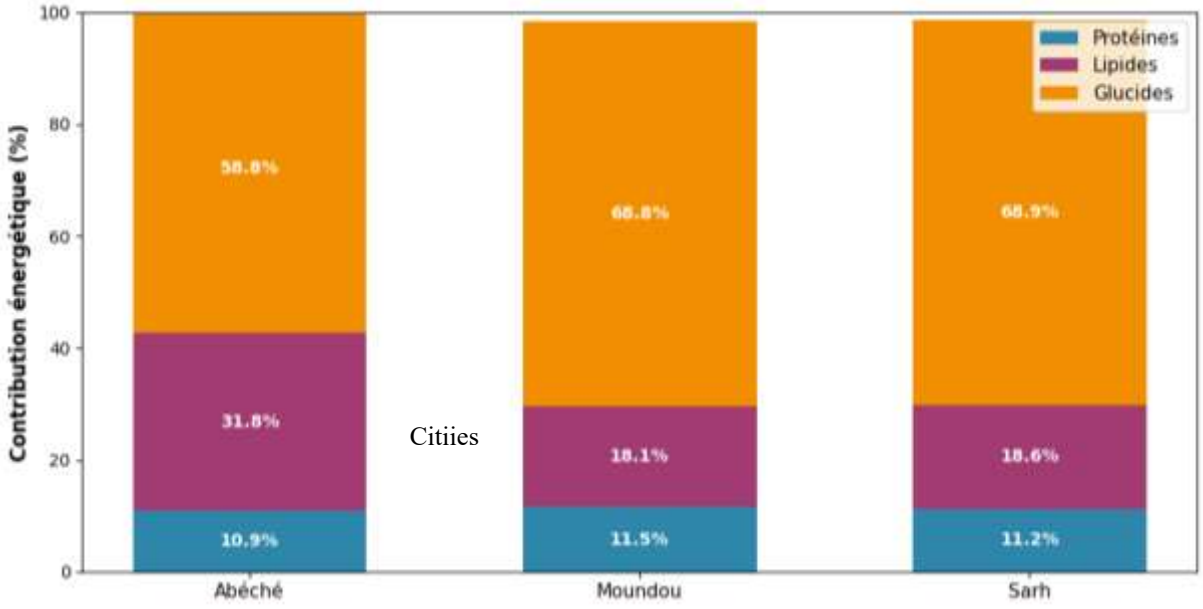

Figure 1: Distribution of energy intake by macronutrient in the complete meal by city

Source : 2023 survey

Energy density analysis reveals that the meal consumed in Abéché is the most energy-dense (235.4 kcal/portion), followed by that of Moundou (215.0 kcal/portion) and that of Sarh (200.3 kcal/portion). The 35 kcal difference between Abéché and Sarh represents approximately 15% of the total energy value of the Sarh meal. The contribution of lipids to total energy intake varies considerably between the three cities: 31.8% in Abéché, compared to only 18.1% in Moundou and 18.6% in Sarh. Conversely, The contribution of proteins is relatively stable (10.9% in Abéché, 11.5% in Moundou, 11.2% in Sarh). Carbohydrates constitute the main energy source in all three cities, contributing 58.8% (Abéché), 68.8% (Moundou), and 68.9% (Sarh).

Limitations:-

Like all scientific research, this study has limitations, such as sample size and representativeness. Although the cities of Abeche, Moundou, and Sarh are among the most important cities in Chad, they do not reflect the full range of the country's food diversity, particularly in a rural areas. Indeed, despite its limitations, this study represents a significant advancement for nutrition in Chad. It provides a solid foundation for further understanding of the impacts of food on population health and for developing nutritional strategies tailored to local realities.

Discussion:-

The aim of this study was to compare the nutritional density of the "corn ball + sauce" meal in three Chadian cities with distinct agro-ecological and culinary contexts: Abéché (East Sahelian), Moundou (agricultural Southwest), and Sarh (riverside South). The results reveal significant heterogeneity in the nutritional composition of the sauces served with the corn ball, while the corn ball itself exhibits relatively similar characteristics across the three sites.
This discussion interprets these results, places them in the context of existing literature, draws out their implications for public health, and identifies the study's limitations.Regarding corn balls, the results show that their nutritional composition varies only slightly between Abéché, Moundou, and Sarh, with the exception of a slightly higher carbohydrate content in Moundou (4.10% compared to 3.75% in Abéché and 3.68% in Sarh). This relative homogeneity was expected, given that the preparation of the balls follows a simple and standardized protocol from one city to another: corn flour, water, and cooking until a homogeneous dough is obtained, without the significant addition of other ingredients.

The protein content of the corn ball (2.58–2.71%) is comparable to those reported in the literature for similar maize-based preparations in sub-Saharan Africa. In Mali,(6) reported protein contents of 2.5% to 3.0% for traditional maize paste. In Cameroon,(7) obtained similar values (2.4–2.9%) for the corn ball consumed in the Far North region. However, these values are lower than the recommended intake for a staple food, highlighting the importance of sauces as a protein supplement.The slightly higher carbohydrate content in Moundou could be explained by differences in the variety of maize used or the degree of cooking. Some studies have shown that starch gelatinization during cooking can influence the extractable carbohydrate content (8). However, this difference, while statistically significant, remains modest and its nutritional impact is probably limited.The moisture content of the ball (31.5-32.2%) is similar to that reported in the literature for African cereal pasta (30-35%) (9). This relatively high water content contributes to the ball's soft texture and palatability, but reduces its energy density per unit mass.

Unlike the corn ball, the sauces exhibit considerable nutritional differences between the three cities, reflecting the diversity of available ingredients and local culinary practices. The sauce from Abéché, prepared with fresh meat, has the highest protein content (3.79%), followed by that from Moundou (3.45%) and that from Sarh (3.12%). This gradient is explained by the nature and quantity of the protein sources used. Fresh beef has an inherently higher protein content (approximately 20% fresh weight) than smoked fish (15-18%), but more importantly, the proportion of the protein ingredient in the sauce appears to be greater in Abéché than in Moundou and Sarh.

This observation aligns with the work of (10) in Burkina Faso, which showed that meat-based sauces were significantly richer in protein than fish-based sauces in West African preparations. Similarly, a study conducted in Niger by (11) reported protein levels of 3.5% to 4.2% for meat sauces compared to 2.8% to 3.5% for fish sauces.
The low protein content of the Sarh sauce (3.12%) is concerning, as it represents the lowest protein contribution in the meal among the three cities. For an adult consuming a standard portion (150g of sauce), the protein intake from the sauce is only 4.7g, less than 10% of the recommended daily intake (approximately 50-60g for a 70kg adult). The most striking difference concerns fat: the Abéché sauce (5.55%) is almost twice as high in fat as the sauces from Moundou (2.89%) and Sarh (2.76%). This difference can be explained by the inherently higher fat content of beef (15-20% fat depending on the cut) compared to smoked fish (5-10%), but also by possible differences in cooking practices (amount of oil added, possible use of fatty offal).Similar results were reported by (12) in Niger, who found lipid contents of 4.8% to 6.2% for meat sauces and 2.1% to 3.5% for fish sauces.

In Chad, (5) also observed that meat-based sauces were significantly higher in lipids than fish-based sauces. From a nutritional standpoint, this difference is ambivalent. On the one hand, lipids are essential for energy intake, the absorption of fat-soluble vitamins (A, D, E, K), and the palatability of meals.

In a context of precarious food security like that of Chad, where a portion of the population is energy deficient, a higher lipid density can be beneficial (13). On the other hand, excessive consumption of saturated fats (those found in beef) can contribute to an increased risk of cardiovascular disease and obesity, emerging phenomena in Chadian cities (3). The sauces from Moundou (81.23%) and Sarh (82.45%) are significantly more watery than that from Abéché (77.84%). This difference reflects distinct culinary practices: in Abéché, the sauce is generally prepared with less water and cooked longer, which concentrates the nutrients; in Moundou and Sarh, the addition of more water and a shorter cooking time result in more diluted sauces.

The high moisture content of sauces in Moundou and Sarh has two major consequences. First, it reduces the nutritional density of the meal: for the same quantity of sauce consumed, the intake of protein, fat, and other nutrients is lower. Second, it can limit total energy intake, particularly in children with reduced gastric capacity (14). Studies conducted in Malawi and Bangladesh have shown that the dilution of sauces and porridges is a major risk factor for childhood malnutrition (15).The estimated energy value of the complete meal (ball + sauce) follows a decreasing gradient from Abéché (235 kcal/portion) to Moundou (215 kcal) and Sarh (200 kcal). This gradient primarily reflects differences in the fat content of the sauces, with fat being the most energy-dense macronutrient (9 kcal/g compared to 4 kcal/g for proteins and carbohydrates).

A portion of a Sarhai meal provides only 200 kcal, which represents less than 10% of an adult's daily energy needs (approximately 2000-2500 kcal depending on the level of physical activity). An adult would therefore need to consume 10 to 12 portions per day to meet their needs, which is difficult to achieve. This low energy density is particularly problematic for vulnerable populations: young children, pregnant or breastfeeding women, the elderly, and the sick, who have increased energy requirements and limited consumption capacity.Conversely, the Abéché meal (235 kcal/portion) is more energy-dense, which is an advantage in a context of precarious food security. However, this higher density stems largely from the meat's fat content, the quality of which (saturated vs. unsaturated fatty acids) was not analyzed in this study.

Indeed, the energy density values obtained in this study (200–235 kcal/portion) are comparable to those reported in other African contexts for similar meals. In Burkina Faso, (16) estimated the energy density of the meal “tô (millet porridge) + sauce” to be between 180 and 250 kcal/portion, depending on the type of sauce. In Mali, (17) reported values of 190–220 kcal for maize porridge with sorrel sauce.However, these values are significantly lower than those observed in Western countries for staple meals. For example, a meal of pasta with Bolognese sauce in France provides an average of 500-600 kcal per serving (18). This difference is explained by the lower energy density of traditional African sauces, which contain less fat and are more watery.This low energy density, while potentially protective against obesity in contexts of abundant food, is problematic in low-income countries where food security is precarious. It can indeed contribute to the chronic energy deficits observed in vulnerable populations (13).

Conclusion:-

This study aimed to compare the nutritional density of the "corn ball + sauce" meal in Abéché, Moundou, and Sarh. The results confirm a significant variability in the sauces, while the corn ball itself remained consistent across the three sites.The sauce from Abéché (meat-based) is richer in protein (3.79%) and fat (5.55%) than those from Moundou and Sarh (fish-based), which are more watery (81-82% versus 78%).

The energy density of the complete meal follows a decreasing gradient : Abéché (235 kcal/portion), Moundou (215 kcal), and Sarh (200 kcal). The fat contribution is twice as high in Abéché (32%) as in Moundou and Sarh (18%).
These results demonstrate that the same staple food can have very different nutritional qualities depending on the local culinary context. For Sarh and Moundou, it is recommended to enrich the sauces by adding legumes, eggs, or fish, and to reduce the amount of water added. For Abéché, the high energy density is an advantage, but the quality of the fats must be monitored.

This study makes an original contribution to our understanding of the nutritional diversity of Chadian meals. It provides essential scientific data to guide nutrition policies and public health programs in the context of the double burden of nutrition. Leveraging local culinary strengths, coupled with targeted improvements, represents a promising avenue for enhancing nutritional security in Chad.

Declaration of competing interest:-
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the trend reported in this paper.

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