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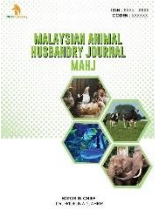

RESEARCH ARTICLE

# TIGERNUT SEED MEAL AS A SUBSTITUTE FOR WHEAT OFFAL: EFFECTS ON NUTRIENT INTAKE AND MILK EFFICIENCY IN LACTATING WEST AFRICAN DWARF DOES

**Caroline Tosin Alade, Teniola Samuel Oso*, Gladys Abiemwense Ibhaze, Desmond Adebowale Okunade**

*Department of Animal Production and Health, Federal University of Technology Akure, PMB 704, Akure, Ondo State, Nigeria*
**Corresponding Author Email: teniolasamuel79@gmail.com*

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## ARTICLE DETAILS

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## ABSTRACT

As global demand for milk increases, nutritional strategies is crucial for improving dairy animal productivity. Thus, a 12-week feeding trial was conducted to evaluate the effects of tigernut seed meal (TSM) on proximate composition, nutrient intake and milk efficiency in West African Dwarf (WAD) goats. Twenty lactating does were randomly assigned to five diets with varying TSM levels: 0% (D1), 5% (D2), 10% (D3), 15% (D4), and 20% (D5) while wilted *Panicum maximum* was fed as basal diet. Proximate composition of the diets, nutrient intake, milk production efficiency, correlation and regression model were analyzed. *Panicum maximum* contained 26.83% dry matter, 8.30% crude protein, and 16.09% crude fiber. Significant ($P<0.05$) differences were observed except for dry matter and nitrogen-free extract. Increased TSM inclusion reduced crude protein (12.01% to 10.55%) and ash content (12.69% to 6.54%) in the diets. Dry matter and crude protein intake declined significantly ($P<0.05$) with TSM, highest values (769.17 g/day and 108.90 g/day) in does fed diet D1. However, highest milk yield (400.89 g/day), efficiency (0.63) and least feed conversion (1.60) was obtained from does fed diet D5. Early lactation showed stronger positive correlations between milk yield and nutrient intake (r = 0.946 for dry matter, r = 0.998 for crude protein), weakening as lactation progressed. Linear and quadratic regression models were both significant ($P<0.05$) in late lactation ($R^2$ = 0.833, r = 0.913; $R^2$ = 0.834, r = 0.913). In conclusion, incorporating up to 15% TSM in lactating goat diets enhances milk yield and efficiency.

**KEYWORDS**

Dairy, Lactation, Milk, Nutrient, Yield

## 1. INTRODUCTION

Milk is a valuable and essential source of high-quality nutrients, providing proteins, fats, vitamins, and minerals required for growth, development, and overall health (Akram et al., 2020, Onyemaechi et al., 2024). Among the various types of milk consumed by humans, goat milk stands out due to its unique composition and superior digestibility (Almasri et al., 2024). Studies have shown that goat milk contains smaller fat globules and a higher proportion of short- and medium-chain fatty acids, making it easier to digest and less likely to cause lactose intolerance compared to cow milk (Roy et al., 2020). Additionally, it is rich in essential amino acids and immunoglobulins, which contribute to improved gut health, enhanced nutrient absorption, and a reduced risk of allergic reactions (Okunlola et al., 2015; Roy et al., 2020).

Despite its nutritional and health benefits, goat milk production is generally low, often due to genetic limitations, small body size, poor management practices, health challenges and inadequate nutrition (Ahuya et al., 2005, Onyemaechi et al., 2024). The quality and quantity of milk produced by dairy goats are heavily influenced by the nutrient composition of diet and overall nutrient intake. Among the most critical dietary components, dry matter intake (DMI) has been found to directly determines the total supply of nutrients available for lactogenesis, while crude fibre supports rumen function and microbial activity, enhancing feed digestibility and nutrient absorption while the body can then direct towards milk production. However, excessive fiber intake can reduce energy availability, necessitating an optimal balance for sustained milk production. Insufficient DMI often leads to negative energy balance, reducing milk yield and compromising the health of lactating does (Overton and Waldron, 2004). Similarly, stated that crude protein (CP) is essential for milk synthesis, providing the amino acids required for casein production and mammary gland function (Gbolahan et al., 2024). A deficiency in amino acids can limit milk yield and reduce protein content, ultimately affecting the nutritional value of the milk.

To enhance milk production, there is a growing need for alternative feed ingredients that can improve nutrient intake and lactogenesis in small ruminants. Tigernut seed meal (TSM) presents a promising substitute due to its rich nutrient profile, including highly digestible fiber, moderate protein content, and essential fatty acids. As reported that replacing cassava peels with tigernut seed meal in a concentrate diet (up to 30%) improved dry matter intake and milk yield in Red Sokoto goats (Ochepo et al., 2016). Additionally, tigernut contains bioactive compounds that enhance general health and performance in growing goats, blood formation, immune function, and reproductive health (Rebezov et al., 2021; Oso et al., 2024). Furthermore, tigernut has been hypothesize to be a galactagogue in nature, capable to stimulate mammary gland and enhance milk production.

Thus, this study aims to evaluate the effects of replacing wheat offal with tigernut seed meal on proximate composition, nutrient intake, and milk efficiency while establishing correlations between milk yield and nutrient intake and developing regression models for milk production prediction.

## 2. MATERIALS AND METHODS

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### 2.1 Experimental Site

The feeding trial for this study was conducted at the Small Ruminant Unit of the Teaching and Research Farm of the department of Animal Production and Health, federal University of Technology Akure, while the laboratory analyses were performed at the Nutrition Laboratory of the same Department. The experimental site is geographically situated between longitudes 4.94°E and 5.83°E and latitude 7.49°N and 6.97°N. This location experiences a wet season for about 6–7 months, with annual rainfall range of 1300–1650 mm and daily temperatures between 27 - 38°C (Daniel, 2015).

### 2.2 Formulation of Experimental Diets

Pre-cleaned dried Tigernuts (*Cyperus esculentus*) were sourced from Shasha market in Akure Ondo State. It was then milled thus referred to as tigernut seed meal (TSM) and substituted for wheat offal at varying levels of 5.00 kg per 100.00 kg such that diet D1 contained 0.00% TSM, 5.00% (D2), 10.00% (D3), 15.00% (D4), and 20.00% (D5) of TSM, while other feed ingredients were kept constant as presented in Table 1. The diets were formulated to meet the nutritional requirements of lactating does, with allowances for both maintenance and lactation. To ensure uniformity and prevent feed ingredient separation, the diets were pelletized into 6 mm pellets. *Panicum maximum* grass was harvested from the natural grass land within the University community and allowed to wilt overnight before chopping to facilitate better mastication.

### 2.3 Experimental Animal Management

A total of 20 lactating West African Dwarf does, with average weight of 13.53 ± 1.17 kg, were selected from the farm's flock. The does were housed individually with their kids in an open-barred pens measuring 6 x 5 feet, equipped with litter, elevated resting platforms. The feeder was positioned such that the kids do not have access to the feed so to facilitate accurate assessment of feed intake. The does were randomly assigned to the formulated experimental diets following a completely randomized design (CRD) with four goats per treatment. Each doe received predetermined portion of the allotted feed in the morning (8:00am) while 400 g/head/day of wilted the wilted *Panicum maximum* was offered in the afternoon (4:00pm) which was considered as basal diet. Clean water was provided *ad libitum* throughout the study.

The feeding trial and sample collection procedures was conducted in compliance with ethical standards approved by the Departmental Research Ethical Committee (Approval No: R/2022/12), adhering to animal research guidelines outlined by (Gross and Tolba, 2015).

**Table 1:** Ingredient Composition (%) of Experimental diets

| Ingredients | D1 | D2 | D3 | D4 | D5 |
|---|---|---|---|---|---|
| Tigernut | 0.00 | 5.00 | 10.00 | 15.00 | 20.00 |
| Wheat Offal | 20.00 | 15.00 | 10.00 | 5.00 | 0.00 |
| Cassava peel | 55.00 | 55.00 | 55.00 | 55.00 | 55.00 |
| Palm kernel cake | 22.00 | 22.00 | 22.00 | 22.00 | 22.00 |
| Dicalcium Phosphate | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Salt | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Sulphur | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| **Total** | **100** | **100** | **100** | **100** | **100** |

### 2.4 Evaluation of nutrient intake and milk efficiency

During the twelve (12) weeks feeding trial, data were collected on feed intake of both the experimental diets and that of *Panicum maximum* which was polled and considered total feed intake. Feed intake was determined by subtracting the leftover from feed offered just as presented as the equation below.

$$\text{Feed intake (g/day)} = \text{Feed Offered} - \text{Leftover Feed}$$

$$\text{Nutrient Intake (g/day)} = \frac{(\text{Nutrient in diet})}{100} \text{ x Feed Intake}$$

The lactating WAD does were hand-milked daily around 7:00 AM before feeding. The collected milk was first measured by volume ($cm^3$) using a graduated glass cylinder and then weighed (g) using a KENWOOD electronic scale (5 kg x 1 g).

Since WAD does were milked only once daily, their actual daily milk production was estimated based on the assumption that milk yield would be higher if they were milked twice a day. To account for this, as weighing factor (0.6596) was applied to the morning milk yield to estimate total daily milk production (Erdman and Verner, 1995):

$$\text{Milk Yield} = M + 0.6596(M)$$

Where: M = Morning milk yield (once-a-day milking)

To ensure accurate measurement, kids were separated from their dams around 6:00 PM on the evening before milking and were fed with milk replacers overnight. After the morning milking session, the kids were reunited with their dams and remained with them until 6:00 PM, ensuring continued nursing and bonding. The average milk efficiency and feed conversion ratio were calculated as:

$$\text{Milk Efficiency} = \frac{\text{Total Milk Yield (g/day)}}{\text{Total Nutrient Intake (g/day)}}$$

$$\text{Feed Conversion} = \frac{\text{Dry Matter Iintake (g/day)}}{\text{(Milk Yield (g/day)}}$$

### 2.5 Laboratory Analysis of the Diets

Sub-samples of the welted grass (*Panicum maximum*) and experimental diets were analysed for proximate composition: dry matter (DM), crude protein calculated (N x 6.25), crude fibre, ash, and ether extract (EE) using the methods according to AOAC (2011). Nitrogen free extract (NFE) was determined using the formula:

$$\%\,\text{NFE} = 100\% - (\%\,\text{Moisture} + \%\,\text{CP} + \%\,\text{CF} + \%\,\text{Ash} + \%\,\text{EE})$$

### 2.6 Statistical Analysis

Proximate composition of *Panicum maximum* was subjected to descriptive statistics of Statistical Package for Social Sciences (SPSS version 25). Data on proximate composition of the formulate diets and nutrient intake was subjected to analysis of variance (ANOVA) of the same statistical package. The differences between means were separated using Duncan's Multiple Range Test of the same statistical package, and the level of significance was taken at $P<0.05$.

The analytical model used was

$$Yij = \mu + ai + eij$$

Where:

Yij = observation in group

μ = Overall mean

ai = Effect of the ith treatment (i = substitution levels diet D1 - D5)

Ɛij – Random error due to experimentation.

Correlation and regression analysis among Milk yield and nutrient intake were carried out using Pearson's Product Moment Correlation Coefficient ®.

Prediction equation between dry matter intake and milk yield, for both linear and quadratic regression models were developed from the same statistical package.

Linear Model: $Y = a + bx$

Quadratic Model: $Y = a + bx + cx^2$

Where:

Y = Milk yield (dependent variable)

x = Dry matter intake (independent variable)

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a = Intercept

b, c = Regression coefficients

## 3. RESULT AND DISCUSSION

### 3.1 Proximate composition (%) of guinea grass (*Panicum maximum*) fed to lactating WAD does

Contained in Table 2 is the proximate composition of *Panicum maximum* fed to lactating WAD does. It was observed that grass contained 26.83% dry matter, 8.30% crude protein, 16.09% crude fiber, 3.79% ether extract, 53.93% nitrogen-free extract, and 6.76% ash content.

Grasses and other plant-based feed resources remain the primary sources of nutrients for ruminant animals. However, during the dry season, these resources may not be sufficient to sustain high production levels, such as lactation. In this study, wilted *Panicum maximum* was used as the basal diet fed at constant rate to the lactating does. The *Panicum maximum* had a relatively low dry matter content (26.83%). This could be attributed to the lush nature, young stage of maturity at harvest, and lignification of the grass, this aligns with the earlier findings of (Ajayi, 2007). Low dry matter content might seem to be a drawback, thus subjecting it to wilting could have actually offers some benefits by encouraging better voluntary feed intake, reduces the risk of microbial or fungal growth on the grass, and lowers the likelihood of metabolic disorders such as bloat (Morgante, 2004; Oso et al., 2024).

The crude protein content of *Panicum maximum* (8.30%) meets the minimum requirement (8.00%) necessary to support rumen function and overall performance in goats. However, this value is slightly lower than the values reported, likely due to variations in weather conditions, maturity stages, and other environmental (edaphic) factors by (Odedire and Babayemi, 2016). The nitrogen-free extract and crude fiber content appear sufficient to promote rumination and provide energy to small ruminants in the form of short-chain fatty acids (Cunha and Shirley, 2012).

The ash content, on the other hand, was lower than the 12.00% reported, which may impact the mineral balance necessary for optimal goat health by (Odedire and Babayemi, 2016). As previously suggested, feeding *Panicum maximum* solely may not be adequate to support the growth and productivity of West African Dwarf (WAD) does by (Oso et al., 2024). Therefore, supplementation with concentrate-based diets is recommended to enhance overall nutritional balance and performance.

**Table 2:** Proximate composition (%) of guinea grass (*Panicum maximum*) fed to lactating WAD does

| | **Mean** | **SEM** |
|---|---|---|
| Dry Matter | 26.83 | 0.13 |
| Crude Protein | 8.30 | 0.11 |
| Crude Fiber | 16.09 | 0.19 |
| Ether Extract | 3.79 | 0.22 |
| Nitrogen-free extract | 53.93 | 0.83 |
| Ash | 6.76 | 0.34 |

Values are mean of triplicates samples, n=3

SEM: Standard error of mean

### 3.2 Proximate composition of diets containing Tigernut seed meal fed to lactating WAD does

Contained in Table 3 is the proximate composition of diets containing varying inclusion of tigernut seed meal (TSM). Significant ($P<0.05$) variation was observed in all parameters except the dry matter and nitrogen-free extract. The dry matter content of the formulated diets (84.29–85.01%) was sufficiently high to support feed intake. According to the study, diets with high dry matter content help inhibit microbial growth, thereby extending feed shelf life, particularly during storage, while also ensuring an adequate nutrient supply for the animals (Ibhaze et al., 2024).

The crude protein and ash content decreases significantly ($P<0.05$) from 12.01% to 10.55% and 12.69% to 6.54% from diet D1 to D5, while crude fiber and ether extract increased from 15.27% to 18.72% and 2.87% to 3.91%. The crude protein (CP) content in this study ranged from 10.55% to 12.01%, exceeding the minimum 8% CP requirement necessary for optimal microbial activity in the rumen (Asaolu et al., 2012). These values also fell within the 9–14% CP range reported for lactating does in early lactation (Mamoon, 2008). This suggests that the diets provided sufficient protein to support effective rumen function and sustain lactating does (Ibhaze et al., 2016). However, a decline in CP content as TSM inclusion increased was observed. This trend is in contrasts with the findings, who reported an increase in CP with tigernut inclusion (Onyemaechi et al., 2024). This discrepancy is likely due to differences in ingredient composition between the two studies.

The CF content in this study exceeded the minimum 12% recommended but comparable to the 11.66–16.38% reported by (Belewu et al., 2007; Mamoon, 2008). However, it was lower than the 21.20–29.25% reported by (Onyemaechi et al., 2024). The moderate fiber content in the formulated diets was beneficial, as it promotes rumination and mastication, improved digestibility, and enhanced feed utilization (Castillo-Lopez et al., 2021). Given that *Panicum maximum* was used as the basal diet in this study along the formulated diets, it is reasonable to assume that the does received adequate amount of dietary crude fiber to support a stable and healthy rumen environment.

Ether extract, which reflects the fat content of the diet, was lower than the values reported by (Belewu et al., 2007). However, the inclusion of TSM increased the fat content, consistent with findings (Belewu et al., 2007). This increase can be attributed to the naturally high oil content of raw tigernut, which contributed to the rise in ether extract levels. The additional fat in the diet could enhance the energy pool through lipid metabolism, thereby improving energy availability for the lactating does.

Nitrogen-free extract, representing the soluble carbohydrate portion of the diet—including monosaccharides, disaccharides, and polysaccharides (such as starch)—was found to be in the range of 41.95–46.01%. This indicates that the diets provided a valuable source of simple and readily available energy for the does. The ash content of the diets decreased as TSM inclusion increased. Nevertheless, the mineral content remained sufficient to support essential biochemical functions, including hormone synthesis, digestive enzymes, fluid balance, lactation and cell development in the animals (Ibhaze et al., 2020).

**Table 3:** Proximate composition of diets containing tigernut seed meal fed to lactating WAD does

| **Parameters (%)** | **Diets** | | | | | **SEM** | ***P*** |
|---|---|---|---|---|---|---|---|
| | **D1** | **D2** | **D3** | **D4** | **D5** | | |
| Dry Matter | 84.79 | 85.01 | 83.66 | 85.17 | 83.29 | 0.22 | 0.07 |
| Crude Protein | $12.01^{a}$ | $11.82^{b}$ | $11.26^{b}$ | $10.92^{c}$ | $10.55^{c}$ | 0.42 | 0.01 |
| Crude Fiber | $15.27^{c}$ | $15.75^{bc}$ | $16.82^{b}$ | $17.38^{ab}$ | $18.72^{a}$ | 0.32 | 0.04 |
| Ether Extract | $2.87^{d}$ | $2.95^{d}$ | $3.38^{bc}$ | $3.45^{b}$ | $3.91^{a}$ | 0.11 | 0.02 |
| Nitrogen-free extract | 41.95 | 44.00 | 43.46 | 46.01 | 43.57 | 1.91 | 0.07 |
| Ash | $12.69^{a}$ | $10.49^{b}$ | $8.74^{c}$ | $7.41^{d}$ | $6.54^{d}$ | 0.59 | 0.02 |

Means within the same row with different superscripts are significantly different ($P<0.05$), SEM= Standard Error of Mean

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### 3.3 Nutrient intake (g/day) by lactating WAD does fed diets containing varying inclusion of tigernut seed meal

The nutrient intake by lactating WAD does fed diets with varying inclusion levels of Tigernut seed meal is presented in Table 4. All values were significantly ($P<0.05$) influenced except the mid dry matter intake, mid and late crude protein. The mean dry matter and crude protein intake decreases significantly ($P<0.04$) with TSM increases, with the highest values (769.17 g/day and 108.90 g/day) from lactating does fed diet D1 and the lowest (732.01 g/day and 97.38 g/day) from does on D5. Conversely, mean crude fiber intake rises significantly ($P<0.03$), with its peak (172.79 g/day) from does fed diet D5. Nutrient intake plays a crucial role in determining an animal's overall performance, health, and productivity. Total dry matter intake is influenced by multiple factors, including the quality and quantity of crude protein, low levels of anti-nutrients, and the physiological status of the animal.

In this study, the relatively high dry matter intake (732.01–769.17 g/day) can be attributed to the nutrient composition of the feed, particularly its crude protein content, as well as the physiological status of the does. Additionally, pelletizing the diets likely contributed to improved intake and digestibility. Pelletizing feed helps bind nutrients together, enhancing palatability and reducing selective feeding, which promotes better nutrient intake and utilization (Oyaniran et al., 2018). However, it is important to note that dry matter intake typically decreases as the lactation progresses in this study from early to late stages. This decline may be due to the body's natural adjustment after parturition and the physiological regression of lactogenesis.

As reported, there was a linear relationship between the crude protein content of the diet, dry matter intake, and crude protein intake by (Omotoso et al., 2023). The observed protein intake was sufficient to support rumen microbial activity, which is essential for fermentation and digestion, as well as to meet the physiological demands for milk synthesis. However, a gradual decline in crude protein intake was observed as lactation progressed, possibly due to shifts in metabolic priorities. The average nitrogen-free extract intake (NFEI) was highest (559.58 g/day) in lactating does fed diet D3 and the least intake (518.30 g/day) from does fed diet D1. Mean ash intake (AI) was found to be highest (115.07 g/day) in does fed diet D1 while the least (60.36 g/day) from goats on diet D5.

Crude fiber and ether extract intake followed a similar pattern; both decreases with lactation but increase as TSM inclusion progresses. These nutrients can help support saliva production and rumination which helps buffer the rumen environment. These components also serve as substrates for rumen microbes, facilitating the production of volatile fatty acids (VFAs) and keto acids, which are critical for energy metabolism and overall physiological function.

Pooled ether extract intake increases significantly ($P<0.01$) from 26.02 g/day (in does fed diet D1) to 36.09 g/day (does fed diet D5). The ether extract intake observed in this study aligns with the findings, who suggested that increased ether extract levels could be linked to the presence of non-drying oils in tigernut rhizomes nor seed (Belewu et al., 2007). These oils contribute to lipid metabolism, which can enhance energy supply and, consequently, support lactation performance. Ash content, which is essential for maintaining electrolyte balance and mineral metabolism, was found to decrease with higher tigernut seed meal (TSM) inclusion.

It is worth emphasizing that voluntary feed and nutrient intake in goats is influenced by multiple factors, including age, breed, physiological status, feed ingredient composition, nutrient and anti-nutrient levels, palatability, feeding conditions, and overall management practices (Omotoso et al., 2023; Ibhaze et al., 2024). Addressing these factors holistically is essential for optimizing nutrient utilization and sustaining milk production efficiency.

**Table 4:** Nutrient intake (g/day) by lactating WAD does fed diets containing varying inclusion of tigernut seed meal

| | | DIETS | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Parameter** | **D1** | **D2** | **D3** | **D4** | **D5** | **SEM** | ***P*** |
| Dry Matter Intake | Early | 792.51$^{a}$ | 781.06$^{b}$ | 775.79$^{c}$ | 771.37$^{c}$ | 750.47$^{d}$ | 87.02 | 0.03 |
| | Mid | 756.08 | 767.34 | 768.08 | 758.07 | 755.13 | 82.03 | 0.07 |
| | Late | 758.93$^{a}$ | 749.23$^{bc}$ | 744.67$^{c}$ | 717.50$^{d}$ | 690.43$^{e}$ | 94.01 | 0.02 |
| | Mean | 769.17$^{a}$ | 765.88$^{ab}$ | 762.85$^{ab}$ | 748.98$^{b}$ | 732.01$^{c}$ | 90.72 | 0.04 |
| Crude Protein Intake | Early | 114.95$^{a}$ | 109.99$^{b}$ | 107.11$^{b}$ | 100.18$^{c}$ | 95.06$^{d}$ | 21.04 | 0.03 |
| | Mid | 107.09 | 109.47 | 104.72 | 94.89 | 96.92 | 16.25 | 0.09 |
| | Late | 104.66 | 106.96 | 104.26 | 89.69 | 100.12 | 18.12 | 0.12 |
| | Mean | 108.90$^{a}$ | 108.80$^{a}$ | 105.37$^{a}$ | 94.89$^{b}$ | 97.38$^{b}$ | 18.90 | 0.03 |
| Crude Fiber Intake | Early | 146.15$^{b}$ | 146.56$^{b}$ | 160.00$^{a}$ | 159.45$^{a}$ | 168.67$^{a}$ | 43.03 | 0.03 |
| | Mid | 136.16$^{d}$ | 145.87$^{c}$ | 156.43$^{b}$ | 151.02$^{b}$ | 171.97$^{a}$ | 41.42 | 0.04 |
| | Late | 133.07$^{d}$ | 142.52$^{c}$ | 155.75$^{b}$ | 142.74$^{c}$ | 177.65$^{a}$ | 38.58 | 0.03 |
| | Mean | 138.46$^{d}$ | 144.98$^{c}$ | 157.39$^{b}$ | 151.03$^{bc}$ | 172.79$^{a}$ | 39.20 | 0.02 |
| Ether Extract Intake | Early | 27.47$^{c}$ | 27.45$^{c}$ | 32.15$^{b}$ | 31.65$^{b}$ | 35.23$^{a}$ | 3.24 | 0.03 |
| | Mid | 25.59$^{d}$ | 27.32$^{cd}$ | 31.44$^{b}$ | 29.98$^{c}$ | 35.92$^{a}$ | 3.75 | 0.05 |
| | Late | 25.01$^{c}$ | 26.69$^{c}$ | 31.30$^{b}$ | 28.33$^{c}$ | 37.11$^{a}$ | 3.63 | 0.02 |
| | Mean | 26.02$^{c}$ | 27.15$^{bc}$ | 31.63$^{ab}$ | 29.98$^{b}$ | 36.09$^{a}$ | 2.90 | 0.01 |
| Nitrogen Free Extract Intake | Early | 547.07$^{c}$ | 548.93$^{c}$ | 568.83$^{a}$ | 558.16$^{b}$ | 543.14$^{c}$ | 97.05 | 0.02 |
| | Mid | 509.70$^{d}$ | 546.35$^{b}$ | 556.17$^{a}$ | 528.66$^{c}$ | 553.75$^{a}$ | 92.96 | 0.01 |
| | Late | 498.14$^{d}$ | 533.78$^{c}$ | 553.73$^{b}$ | 499.68$^{d}$ | 572.06$^{a}$ | 85.02 | 0.02 |
| | Mean | 518.30$^{d}$ | 543.00$^{b}$ | 559.58$^{a}$ | 528.70$^{c}$ | 556.38$^{a}$ | 94.32 | 0.03 |
| Ash Intake | Early | 121.45$^{a}$ | 97.61$^{b}$ | 83.14$^{c}$ | 67.98$^{d}$ | 58.93$^{e}$ | 8.06 | 0.02 |
| | Mid | 113.16$^{a}$ | 97.16$^{b}$ | 81.29$^{c}$ | 64.39$^{d}$ | 60.08$^{d}$ | 7.57 | 0.02 |
| | Late | 110.59$^{a}$ | 94.92$^{b}$ | 80.93$^{c}$ | 60.86$^{d}$ | 62.07$^{d}$ | 8.32 | 0.02 |
| | Mean | 115.07$^{a}$ | 96.56$^{b}$ | 81.78$^{c}$ | 64.39$^{d}$ | 60.36$^{e}$ | 8.04 | 0.01 |

$^{abcd}$Means within the same row with different superscripts are significantly different ($P<0.05$)

SEM= Standard Error of Mean

D1= (Control diet) 0% Tigernut inclusion with 20% Wheat offal: (0.00% replacement)

D2= 5% Tigernut inclusion with 15% Wheat offal: (25.00% replacement)

D3 = 10% Tigernut inclusion with 10% Wheat offal (50.00% replacement)

D4 = 15% Tigernut inclusion with 5% Wheat offal (75.00% replacement)

D5 = 20% Tigernut inclusion with 0% Wheat offal (100.00% replacement)

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### 3.4 Feed intake and milk efficiency of lactating WAD does fed diets containing varying inclusion of tigernut seed meal

Shown in Table 5 is the feed intake and milk efficiency of lactating WAD does fed diets containing varying inclusion of tigernut seed meal. All parameters were significantly ($P<0.05$) different except the mid dry matter intake by the lactating does.

Average feed intake was highest (935.75 g/day) in does fed diet D3, while does on diet D4 had the lowest (869.00 g/day) intake. However, early, late and mean dry matter intakes (DMI) decreased significantly ($P<0.05$) with TSM inclusion, with does fed D1 showing the highest value (792.51 g/day, 758.93 g/day and 769.17 g/day) and does on diet D5 having the lowest (750.47 g/day, 690,43 g/day and 732.01 g/day) DMI.

The mean feed dry matter intake (869.00–935.75 g/day) observed in this study was lower than the range of 961.33–2086.96 g/day reported when lactating WAD does were fed *Panicum maximum* supplemented with a Bambara groundnut meal-based concentrate by (Odoemelam et al., 2013). The pattern of dry matter content in the diet was found to have a direct and proportionate influence on average feed intake, suggesting that the does consumed feed according to their dietary needs.

A decline in dry matter intake was observed as lactation progressed, a common trend in living organism as the body system undergo metabolic adjustments post-parturition. Additionally, an overall decrease in dry matter intake was recorded with increasing levels of TSM, indicating its potential influence on feed consumption.

Interestingly, despite the reduction in dry matter intake, milk yield increased with higher TSM inclusion. However, as lactation advanced, a natural decline in milk production was observed, consistent with well-documented lactation physiology in dairy animals. The involution of the mammary gland after peak lactation is the gradual regression in milk synthesis, an irreversible biochemical process influenced by both mammary gland and brain cell interactions. Peak production and onset of lactation regression is species-dependent, management system and nutrition plan, reduction in milk yield in goat is usually after 4 to 5 weeks. Similar trends were reported in Red Sokoto goats, Yankasa sheep, and WAD ewes, where milk production peaked within 2–5 weeks post-partum before gradually decreasing (Adewumi, 2002).

The milk yield of the lactating WAD does were found to increase significantly ($P<0.05$) with TSM inclusion. The highest average milk yield was observed in does fed diet D5 (389.22 cm$^3$/day and 400.89 g/day), while does on D1 had the lowest (359.80 cm$^3$/day and 370.59 d/day) mean milk yield. Interestingly, milk yield was found to regress significantly ($P<0.05$) as lactation period progresses as presented in Figure 1.

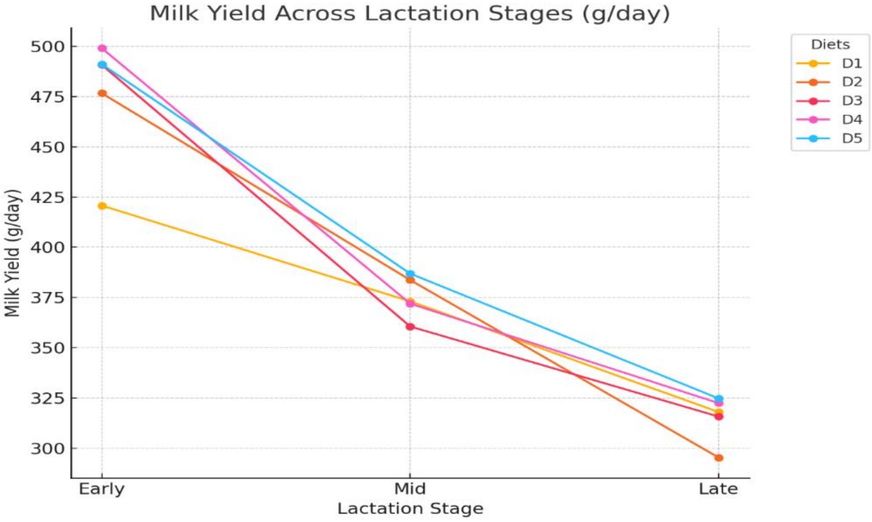

**Figure 1:** Milk production pattern of lactating WAD does across Early, Mild and Late lactation stages

The highest daily milk yield (400.89 g/day) was observed in goats fed diet T5, which may be attributed to the availability of essential nutrients. As previously reported that does fed a diet containing 30% TSM had increased ruminal propionic acid production, which directly influences milk volume, as propionate is a key precursor in milk synthesis (Ibhaze et al., 2024). Furthermore, TSM may contain bioactive compounds with galactagogue properties, which could enhance mammary gland development and lactation performance, potentially through stimulation of prolactin expression and pituitary gland activity (Hannan et al., 2023). Litter size also played a role in daily milk yield (DMY), as hormonal regulation during pregnancy influences udder development and milk production. A good portion of the does had two kids in this study. As noted that does nursing multiples kids experience higher hormonal stimulation for milk production, leading to increased milk synthesis compared to does nursing single kid (De Passillé et al., 2008).

Compared to exotic dairy breeds, the daily milk yield observed in this study was relatively low. However, this is expected, as WAD goats are dual-purpose goats rather than high-yield dairy breeds (Ahamefule et al., 2012). One potential strategy to improve milk yield is increasing milking frequency. As reported a 52.7% reduction in milk yield when goats were milked once daily, suggesting that milking twice or more per day could significantly enhance production efficiency (Sam et al., 2018). Earlier studies also confirmed that more frequent milking results in higher milk yields due to sustained stimulation of milk letdown and secretion by (Stockdale, 2006).

Feed conversion to milk and feed efficiency were in inverse. Does fed diet D5 showing the highest efficiency (0.63) and least feed conversion of 1.60 per dry matter intake, while does fed diet D1 had the lowest (0.48) feed efficiency and highest fed conversion (2.08). Feed conversion and efficiency values were relatively on the average in this study, with the highest (0.63) efficiency and least FCR (1.60) recorded in does fed diet D5. This implies that 63% of the dry matter were converted or directed to milk production while a unit production of milk (g) may require the does to consume 1.60g of dry matter. This is however, statistically similar to 0.57 and 1.77 obtained from does on diet D4. High-yielding animals tend to be more energetically efficient, as a larger proportion of ingested energy is allocated to milk synthesis rather than maintenance, in contrast to lower-producing animals (Linn et al., 2007).

Milk yield and nutrient intake by dairy WAD does are influenced by several factors, including feeding strategies, frequency of milking, physiological status, hormonal balance, parity, breed, stage of lactation, litter size, season of kidding, maternal age, and the combined effect of parity-year-season interactions (Sevi et al., 2009; Oso et al., 2024). Understanding these factors is essential for optimizing dairy production in WAD goats.

**Table 5:** Feed intake and milk efficiency of lactating WAD does fed diets containing varying inclusion of tigernut seed meal

| | | DIETS | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Parameter** | **D1** | **D2** | **D3** | **D4** | **D5** | **SEM** | ***P*** |
| Total feed intake as fed (g/day) | Early | 957.08$^{a}$ | 930.55$^{b}$ | 951.22$^{a}$ | 917.42$^{c}$ | 901.03$^{d}$ | 59.39 | 0.02 |
| | Mid | 891.71$^{c}$ | 926.17$^{b}$ | 930.05$^{a}$ | 868.93$^{d}$ | 918.63$^{bc}$ | 51.40 | 0.03 |
| | Late | 871.48$^{c}$ | 904.87$^{b}$ | 925.97$^{ab}$ | 821.30$^{d}$ | 949.01$^{a}$ | 54.90 | 0.01 |
| | Mean | 906.75$^{a}$ | 920.50$^{a}$ | 935.75$^{a}$ | 869.00$^{b}$ | 923.00$^{a}$ | 57.12 | 0.01 |

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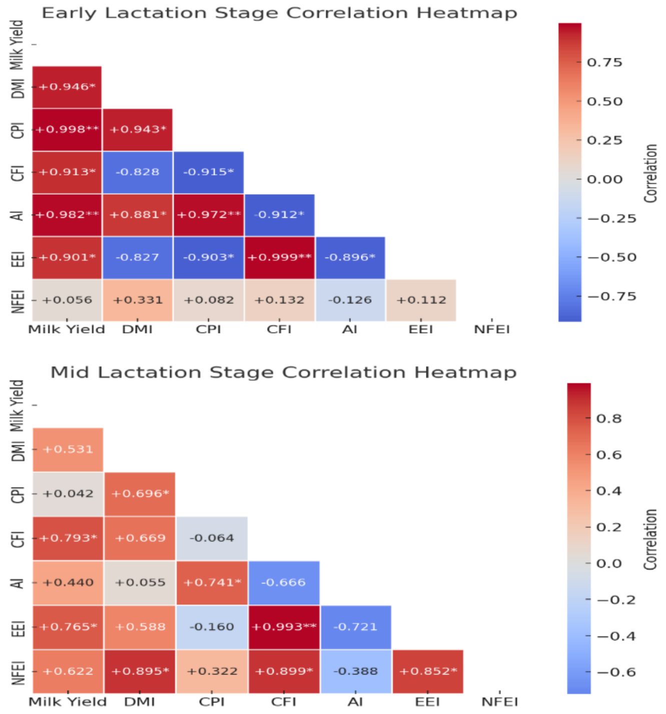
**Table 5 (cont):** Feed intake and milk efficiency of lactating WAD does fed diets containing varying inclusion of tigernut seed meal

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Dry matter intake (g/day) | Early | 792.51$^{a}$ | 781.06$^{b}$ | 775.79$^{c}$ | 771.37$^{c}$ | 750.47$^{d}$ | 87.02 | 0.03 |
| | Mid | 756.08 | 767.34 | 768.08 | 758.07 | 755.13 | 82.03 | 0.07 |
| | Late | 758.93$^{a}$ | 749.23$^{bc}$ | 744.67$^{c}$ | 717.50$^{d}$ | 690.43$^{e}$ | 94.01 | 0.02 |
| | Mean | 769.17$^{a}$ | 765.88$^{ab}$ | 762.85$^{ab}$ | 748.98$^{b}$ | 732.01$^{c}$ | 90.72 | 0.04 |
| Milk Yield (cm$^{3}$/day) | Early | 408.50$^{c}$ | 462.80$^{b}$ | 476.50$^{a}$ | 484.54$^{a}$ | 476.80$^{a}$ | 31.49 | 0.01 |
| | Mid | 362.20$^{b}$ | 372.50$^{a}$ | 350.05$^{c}$ | 361.08$^{b}$ | 375.60$^{a}$ | 16.54 | 0.01 |
| | Late | 308.70$^{c}$ | 286.70$^{d}$ | 306.50$^{c}$ | 313.00$^{b}$ | 315.25$^{a}$ | 19.71 | 0.02 |
| | Mean | 359.80$^{c}$ | 374.00$^{b}$ | 377.68$^{b}$ | 386.21$^{a}$ | 389.22$^{a}$ | 22.58 | 0.01 |
| Milk Yield (g/day) | Early | 420.76$^{d}$ | 476.68$^{c}$ | 490.80$^{b}$ | 499.08$^{a}$ | 491.10$^{b}$ | 32.43 | 0.03 |
| | Mid | 373.07$^{b}$ | 383.68$^{a}$ | 360.55$^{c}$ | 371.91$^{b}$ | 386.87$^{a}$ | 17.04 | 0.02 |
| | Late | 317.96$^{c}$ | 295.30$^{d}$ | 315.70$^{c}$ | 322.39$^{b}$ | 324.71$^{a}$ | 20.30 | 0.02 |
| | Mean | 370.59$^{c}$ | 385.22$^{b}$ | 389.01$^{b}$ | 397.79$^{a}$ | 400.89$^{a}$ | 23.26 | 0.03 |
| Feed Conversion | Early | 1.88$^{a}$ | 1.64$^{b}$ | 1.55$^{b}$ | 1.39$^{cd}$ | 1.24$^{d}$ | 0.12 | 0.01 |
| | Mid | 2.03$^{b}$ | 2.00$^{b}$ | 2.13$^{a}$ | 2.04$^{b}$ | 1.68$^{a}$ | 0.34 | 0.02 |
| | Late | 2.39$^{b}$ | 2.54$^{a}$ | 2.36$^{b}$ | 2.09$^{c}$ | 2.13$^{c}$ | 0.23 | 0.02 |
| | Mean | 2.08$^{a}$ | 1.99$^{a}$ | 1.94$^{a}$ | 1.77$^{b}$ | 1.60$^{b}$ | 0.21 | 0.03 |
| Feed Efficiency (Milk g/g of DMI) | Early | 0.53$^{e}$ | 0.61$^{d}$ | 0.65$^{c}$ | 0.72$^{b}$ | 0.80$^{a}$ | 0.07 | 0.02 |
| | Mid | 0.49$^{b}$ | 0.50$^{b}$ | 0.47$^{b}$ | 0.49$^{b}$ | 0.59$^{a}$ | 0.05 | 0.01 |
| | Late | 0.42$^{a}$ | 0.39$^{a}$ | 0.42$^{b}$ | 0.48$^{a}$ | 0.47$^{a}$ | 0.04 | 0.02 |
| | Mean | 0.48$^{c}$ | 0.50$^{b}$ | 0.51$^{b}$ | 0.57$^{a}$ | 0.63$^{a}$ | 0.05 | 0.02 |

$^{abcd}$ Means within the same row with different superscripts are significantly different (*P*<0.05)
SEM= Standard Error of Mean
D1= (Control diet) 0% Tigernut inclusion with 20% Wheat offal: (0.00% replacement)
D2= 5% Tigernut inclusion with 15% Wheat offal: (25.00% replacement)
D3 = 10% Tigernut inclusion with 10% Wheat offal (50.00% replacement)
D4 = 15% Tigernut inclusion with 5% Wheat offal (75.00% replacement)
D5 = 20% Tigernut inclusion with 0% Wheat offal (100.00% replacement)

### 3.5 Pearson's correlation among milk yield and nutrient intake of WAD does fed diets containing varying inclusion of tigernut seed meal

At the early lactation stage, milk yield showed strong positive correlations with dry matter intake (DMI) (r = 0.946), crude protein intake (CPI) (r = 0.998), and ash content intake (ASI) (r = 0.982) as seen in Figure 2. Crude fiber intake (CFI) exhibited a negative correlation (r = -0.915) with CPI, DMI (-0.828) and positive correlation with milk yield (r = 0.913). A strong positive correlation (r = 0.999) was observed between ether extract intake (EEI) and CFI. However, nitrogen-free extract (NFEI) showed a weak correlation with milk yield (r = 0.056). During early lactation, crude protein, dry matter, and ash content play a critical role in driving milk yield as there was high correlation coefficient between these nutrients and milk yield. This highlights the necessity of a nutrient-dense diet to support the onset and peak of milk production. A strong positive correlation between milk yield and nutrient intake suggests that optimal milk production is largely dependent on the provision of high-quality nutrients in the diets. Adequate dietary crude protein at this stage is particularly crucial, as it supports rumen microbial activity, milk synthesis, and metabolic recovery post-partum.



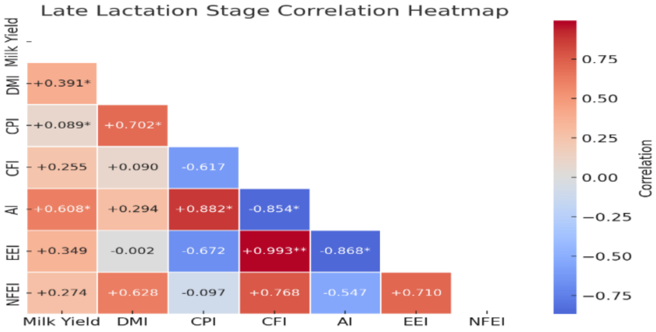


**Figure 2:** Pearson's correlation among milk yield and nutrient intake at different stages by WAD does fed diets containing wheat offal substituted for tigernut seed meal

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

DMI: Dry matter intake; CPI: Crude protein intake; CFI: Crude fibre intake; AI: Ash intake; EEI: Ether extract intake; NFE: Nitrogen free intake

During mid lactation, milk yield had a moderate positive correlation with DMI (r = 0.531) and crude fiber (r = 0.793), but the relationship was not statistically significant. However, CPI showed a weak correlation with milk yield (r = 0.042) as shown in Figure 2, unlike in the early stage where protein intake was a strong predictor of milk yield. The significant positive correlation between EEI and CFI (r = 0.993), while NFEI exhibited a positive significant correlation with DMI (r = 0.895) and crude fiber (r = 0.899) and EEI (r=0.652) (A seen in Figure 2).

As lactation progresses, correlation coefficient values between milk yield and crude protein intake decline, as correlation values showed the role of ether extract, crude fiber, and nitrogen-free extract (NFE) in milk production. This shift suggests that the crude protein content in the diet during mid-lactation may be insufficient to support both maintenance and milk production needs. It emphasized the necessity of increasing crude protein levels to 12–14% in the diet of lactating does to sustain optimal milk production (Mamoon, 2008). Furthermore, a positive correlation between crude fiber, ether extract, and milk yield at the mild stage of lactation suggests that these nutrients become increasingly important for energy metabolism and sustained milk synthesis. This finding underscores the need to adjust crude protein levels in mid-lactation to maintain high milk production efficiency (Yogeshpriya et al., 2024).

At the late lactation stage, milk yield had a weak but significant correlation with DMI (r = 0.391). The correlation between CPI and milk yield (r = 0.089) was lower than in earlier stages. Ash content was positively correlated with CPI (r = 0.882). The strong negative correlation (r = -0.868) between EEI and AI and a significant positive correlation (r = 0.993) with CFI.

In late lactation, there is a further decline in the correlation coefficients between nutrient intake and milk yield, indicating a gradual shift in metabolic priorities. This reduction suggests that as lactation advances, nutrient requirements increase overall, necessitating more energy to sustain residual milk production while also preparing the doe's body for the next reproductive cycle (Overton and Waldron, 2004; Yogeshpriya et al., 2024).

### 3.6 Regression equations for dry matter intake and milk yield WAD does fed diets containing wheat offal substituted for tigernut seed meal

Presented in Table 6 is the predictive equation for milk yield by WAD does fed diets containing wheat offal substituted for TSM. In early lactation, the linear regression model was significantly (*P*<0.05) influenced, with the coefficient of determination ($R^2$) of 0.895 and a strong positive correlation (r = 0.946). The quadratic model on the other hand has a slightly higher $R^2$ (0.933) and correlation (r = 0.966). According to the study, dry matter intake (DMI) is one of the most critical and reliable factors in estimating milk production in lactating dairy animals (Lee et al., 2020). In this study, the predictive equation developed to estimate milk yield using DMI as the independent variable showed variations across different lactation stages. However, during mid-lactation, the equation was not statistically significant. To assess the accuracy and precision of the model, three commonly used statistical indicators are: the coefficient of determination ($R^2$), mean bias, and Root Mean Square Prediction Error (RMSPE) (Hoffman et al., 2008).

In mid-lactation, neither model is statistically significant. The linear model had a low $R^2$ with a value of 0.282, with a moderate correlation (r = 0.532). The quadratic model shows a stronger relationship with $R^2$ = 0.624 and r = 0.790, but remains significantly not significant (*P*>0.05). In late lactation, both models are statistically significant. The linear regression model had a $R^2$ value of 0.833, with a strong correlation (r = 0.913) while its quadratic model performs similarly with $R^2$ = 0.834, r = 0.913.

The coefficient of determination ($R^2$) for the milk yield was relatively high during early and late lactation, indicating that DMI effectively explained milk yield variability at these stages. Specifically, the linear regression model yielded $R^2$ values of 0.895 for early lactation and 0.833 for late lactation, suggesting that 89.50% and 83.33% of the milk yield could be attributed to DMI at these respective stages. Higher $R^2$ values indicate a better model fit and stronger explanatory power of the independent variable (Liang et al., 2021).

Although not statistically significant, the quadratic regression model showed higher $R^2$ values for early (0.933) and mid lactation (0.624). This suggests that while a quadratic model may capture additional variation, the linear model remains sufficient for estimating and predicting milk yield based on DMI in these lactation phases. These findings indicate that linear model performed reasonably well in terms of accuracy and precision in estimating daily DMI and its impact on milk production.

One key limitation to these developed models is the small dataset size (n = 20). Model fitness and reliability typically improve with larger datasets, as regression equations developed on larger sample sizes tend to be more reliable and less sensitive to random variations (Jensen et al., 2015).

In developing industrial application of these models, more extensive dataset should be used so to enhance its predictive power and ensure broader applicability. Additionally, the model's accuracy may be influenced by species and breed variations, feeding management systems, lactation stages, milking method and frequency.

**Table 6:** Regression equation for dry matter intake and milk yield WAD does fed diets containing wheat offal substituted for tigernut seed meal

| | Parameters | Regression Equation | SE | R² | r | P-Valve | Sig |
|---|---|---|---|---|---|---|---|
| Early | Linear | Y= 2750.37 – 2.867 x | 25.70 | 0.895 | 0.946 | 0.015 | * |
| | Quadratic | Y = -15184.535 + 43.193 -0.030 x | 25.17 | 0.933 | 0.966 | 0.067 | ns |
| Mid | Linear | Y = - 3.215 + 0.503 x | 33.377 | 0.282 | 0.532 | 0.357 | ns |
| | Quadratic | Y = 12174.620 -32.318 + 0.022 x | 29.580 | 0.624 | 0.790 | 0.376 | ns |
| Late | Linear | Y = 947.950 – 0.834 x | 7.979 | 0.833 | 0.913 | 0.031 | * |
| | Quadratic | Y = 629.834 - 4.349 – 0.001x | 7.960 | 0.834 | 0.913 | 0.030 | * |

* Significant (*p*<0.05), SE: Standard error, ns = Not significant, Y = Dependent Variable (Milk yield), x = Independent Variable (Dry matter intake)

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## 4. CONCLUSION

This study highlights the potential of tigernut seed meal (TSM) as a viable alternative to wheat offal in the diet of lactating goats. The findings indicate that a 15% inclusion level of TSM enhances nutrient intake, feed efficiency, and average milk yield, making it a promising substitute, particularly during off-seasons when conventional feed ingredients are scarce.

Additionally, the study reaffirms that dry matter and crude protein content and intake are critical determinants of milk yield in lactating does. Furthermore, the linear regression model proved to be a reliable tool for estimating milk yield over the quadratic model, suggesting its practical applicability in dairy industry.

## RECOMMENDATIONS

From this study, the following recommendations are made

- Tigernut seed meal (TSM) can serve as a viable alternative to wheat offal in the diets of lactating WAD does, with an optimal inclusion level of 15%.
- Further research is needed to assess the effects of TSM on milk composition, including its influence on fat, protein, and lactose content.
- Future studies should utilize larger datasets to develop a more robust and reliable predictive model for milk yield so to facilitate it industrial application.

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