# NUTRIENT FORAGING ABILITY OF SELECTED LOCAL PEANUT (*Arachis hypogaea*) VARIETIES UNDER DROUGHT STRESS

## ABSTRACT

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| **Background:** Peanuts (*Arachis hypogaea L.*) are an important oleaginous food, widely cultivated in tropical and semiarid regions, where drought is one of the most limiting factors for production. Nutrient foraging is the ability of plants to efficiently explore and exploit the soil environment in order to acquire essential nutrients for their growth and development.  **Aim:** This study aimed to investigate the nutrient foraging ability of some peanut varieties under drought conditions.  **Method:** The study was carried out at the Screen-house of the Department of Biological Sciences at Yelwa Campus of Abubakar Tafawa Balewa University; Bauchi State, Nigeria, between August-September, 2024. The study was conducted as a complete randomised design with three replicates. A 4x3 factorial design; the 4 varieties of peanut were subjected to 3 different water regimens (5 days, 10 days and 15 days interval with a control which received a regular watering). Nutrients analysed include: K, Na, Ca, Cu, Mn, Fe and Zn. Descriptive analysis was used to calculate the means and percentage of the varieties. Analysis of variance (ANOVA) was used to compare the means of the growth, yield and phenotypic parameters. Duncan’s Multiple Range Test (DMTR) was used to separate the means where significant.  **Results:** Based on the variation in terms of physiological susceptibility among the varieties, Bahausa had the highest plant height (25.7cm), longest leaves (3.89cm) and most leaves (21) while Yar Dakar and Kampala had shorter plants, shorter leaves and fewer leaves. This is clearly indicates that Bahausa appears least physiologically susceptible to drought, as it maintains growth despite the stress. Yar Dakar and Kampala, with significantly lower values (especially in leaf traits), show higher physiological susceptibility, which means the drought stress more severely disrupted their growth processes. Jaye is intermediate in performance, slightly more susceptible than Bahausa, but less than Kampala and Yar Dakar. The different letters (a,b,c) next to the mean value indicate statistically significant differences at p≤ 0.05. These differences confirm that the peanut varieties have genetically inherited traits affecting their growth rates, leaf size, and ability to produce foliage under drought.  **Conclusion**: The effects of drought stress on the overall growth of the peanut varieties were not apparent until at the later stage of growth and Bahausa variety accompanied by Jaye were least affected. The same cannot be said for the effect of drought on the overall yield of peanut varieties, since Kampala variety excelled above all varieties, with Yar Dakar variety following in its lead. Those peanut varieties with enhanced nutrient foraging ability under drought conditions were Bahausa and Kampala, respectively. |

*Keywords: Nutrients; foraging; peanut; drought stress.*

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## 1. INTRODUCTION

Peanuts (*Arachis hypogaea L.*) are an important oleaginous food, widely cultivated in tropical and semiarid regions, where drought is one of the most limiting factors for production. They are a vital oilseed, food, and feed legume grown in more than 100 countries (Pereira et al*.,* 2016; Emara et al*.,* 2023). The cultivated area and production increased marginally during the last few years; in 2019 it was around 35 million ha with a total production of 73 million tons (FAOSTAT, 2022; Emara et al*.,* 2023), and it continually increasing.

Peanut is known to be more drought-tolerant than most other related species (Wan et al*.,* 2014), but drought conditions also have a negative impact on growth and seed quality, as well as significantly reducing pod yield (Boontang et al*.,* 2010; Shrief et al*.,* 2020; Emara et al*.,* 2023). The accumulation of biomass in peanut is correlated to the amount of applied water from emergence to the start of flowering, and sensitivity to water stress increases progressively during the reproductive phase, which affects pod production on the plant (Faye et al*.,* 2016; Rachaputi et al*.,* 2021). For example, Aydinsakir et al*.,* (2016), Garko et al*.,* (2016), and Ngulube et al*.,* (2018) reported that applying 100 % plant water requirements resulted in biomass yields of more pods number greater than 70 and 40 %, respectively.

Drought stress, particularly during critical growth stages such as flowering and pod-filling, significantly reduces peanut (*Arachis hypogaea*) yield by impairing photosynthesis, inhibiting biomass accumulation, and disrupting nitrogen fixation (Pokhrel et al*.,* 2024; Sharma et al*.,* 2024). In a controlled-saline trial, the HY25 peanut variety exhibited a marked decline in photosynthetic rate (Pn), SPAD chlorophyll content, leaf area, and ultimately pod yield when subjected to short-term drought at 40 days after planting, the most sensitive growth stage observed (Zhang et al*.,* 2023). Further, drought combined with salinity stress reduced 100-pod and 100-kernel weight by 15–58%, highlighting the exacerbating effect of multiple abiotic stresses (Zhang et al*.,* 2023). Concurrently, high-oleic peanut varieties assessed in China (2022–2023) demonstrated yield losses ranging from 9.7% to 49.2% under drought conditions, with pronounced reductions in agronomic indicators such as pod number per plant and dry biomass (Jin et al*.,* 2025). Such varietal differences emphasise the need for breeding programs to focus on drought-resilient traits; indeed, cultivars like Jihua 1353 and Jihua 712 have been identified as drought-tolerant based on multiple stress indices (Jin et al*.,* 2025).

Drought tolerance may be increased by varieties with a distributed root that extracts water from the majority of the soil profile (Songsri et al*.,* 2008; Emara et al*.,* 2023), which may result in increased pod yield and harvest index (Abou Kheira, 2009). Furthermore, Meena et al*.,* (2014) and El-Far et al*.,* (2016) found significant differences in water regime on yield and component in two peanut cultivars (Giza and Sohage 104).

The Giza cultivar significantly surpassed Sohag 104 in all yield traits. These studies supported that variation in water regime can influence the physiological activities of one variety over another.

Nutrient foraging is the ability of a plant to efficiently search for essential nutrients for their growth and development. Higher plants predominantly absorb mineral nutrients through the roots and uptake is determined by both supply and demand at the root surface (Bederedse et al*.,* 2007, Silva et al*.,* 2011). Nutrient uptake by plants is a very effective process due to the large surface area of the roots and their ability to absorb microelement ions at low concentrations in the soil solution. However, most nutrients are dependent on soil moisture to move through the soil matrix and be taken up by plants (Taiz and Zeiger, 2006, Silva et al*.,* 2011). In addition to the effect of water on plant growth and development, Nutrient availability also affects plant root development and water uptake (Kong et al*.,* 2017; Song et al*.,* 2019). Generally, Nutrient availability can promote root growth and improve root activity under drought conditions (Xu et al*.,* 2018; Zhang et al*.,* 2022). The ability to absorb nutrients and water can be improved by root development, thus enhancing the resistance of plants to abiotic stress (Abid et al*.,* 2016; Zhang et al*.,* 2022). However, nutrients may play different roles under different soil moisture conditions. This indicates that there is a strong association between the drought and nutrient foraging.

According to Dinh et al*.,* (2014) revealed that like other crops, peanut requires essential nutrients during its life cycle. However, most nutrients are taken up into the plant in the forms of soluble inorganic fertilisers by the root system; therefore, water stress reduces nutrient absorbability and nutrient foraging of the plant (Baligar et al*.,* 2001; Fageria et al*.,* 2002; Dinh et al*.,* 2014). The reductions in nutrient foraging caused by drought have been reported during certain developmental stages of peanut, including pod formation, pegging and pod-filling (Kulkarni et al*.,* 1988; Kolay, 2008; Dinh et al*.,* 2014). Moreover, nutrition balance is a key factor in diminishing environmental risks and promoting healthy plants with sustainable growth, yield, and quality (Magen, 2008; Dinh et al*.,* 2014). Improvement of nutrient forgaing, therefore, is necessary to maintain acceptable growth and yield under drought.

Previous studies have reported that the accumulation of minerals under drought conditions might be an important trait of drought tolerance in some plant species, including tall fescue (Huang, 2001), soybean (Samarah et al*.,* 2004), and chickpea (Gunes et al*.,* 2006). However, differential responses among species for nutrient foraging under drought stress were not observed.

It is still in doubt on which of the peanut varieties and at what level of nutrient foraging under drought conditions will be more tolerant in terms of productivity. Therefore, this study aimed to investigate the nutrient foraging ability of some peanut varieties under drought conditions. The results will provide a better understanding of peanut response to nutrient foraging under drought conditions and as well an appropriate provision on breeding strategies for drought resistance in peanuts.

## 2. MATERIALS AND METHODS

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### 2.1 Study Area

The field study was carried out at the Screen-house of the Department of Biological Sciences at Yelwa Campus of Abubakar Tafawa Balewa University, Bauchi State, Nigeria. Sample analysis was conducted at Laboratory 5, Department of Automobile Engineering, Abubakar Tafawa Balewa University, Bauchi State, Nigeria. The experimental site lies within the savanna agro ecological zone of North East Nigeria (latitude: 10.7761°N, longitude 9.9992°E). Bauchi has a rainfall pattern that typically peaks in August with an annual rainfall of 85.87 mm, which has 115.72 rainy days. Temperatures are fairly uniform, with values of 21°C to 34°C annually. The highest temperature is recorded in April during the dry season. Relative humidity is high during the rainy season, reaching up to 30%.

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### 2.2 Sample Collection

The local seed varieties were sourced from local farmers within Jos (Jaye), Niger (Yar Dakar), Kaduna (Bahausa), and Sokoto (Kampala).

### 2.3 Experimental Design

The study was conducted as a complete randomised design with three replicates. A 4x3 factorial design; the 4 varieties of peanut were subjected to 4 different water regimen (5 days, 10 days and 15 days interval with a control which received a daily watering). The screen-house designated for the field study was cleared, planting pots of 5 liter were arranged, filled with garden soil, and properly irrigated before planting.

**2.4 Pre-planting (Nutrient) Analysis**

A seed viability test was carried out on the seed using the floating method (Singh et al*.,* 2013). Viable seeds were used, and non-viable seeds were discarded. Each variety of seed was sampled and analysed to determine the nutrient composition of the seed using the aqua-regia digestion method (Ozyigit and Bilgen, 2012) before planting. Nutrients analysed include Macro and Micro nutrients such as: Potassium (K), Sodium (Na), Calcium (Ca), Copper (Cu), Manganese (Mn), Iron (Fe) and Zinc (Zn) (Ayoola et al*.,* 2017). The garden soil was sampled and analysed to determine the pre-planting nutrient status of the soil. Potassium (K), Sodium (Na), Calcium (Ca), Copper (Cu), Manganese (Mn), Iron (Fe) and Zinc (Zn) (Ayoola et al*.,* 2017). The nutrient analysis for macro and micro elements was conducted using Atomic Absorbance Spectroscopy (AAS) calibrated at 1/1000 (ppm).

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### 2.5 Growth and Yield

Days to germination, days to flowering after planting were recorded (Singh, 2017). The peanut pods were removed from the plant and fresh materials (without pods) were weighed per plant in the field to determine fresh fodder/haulm yield (kg.ha-1) (Singh, 2017). Above-ground materials (leaf + stem) were dried in an oven at 80°C for 48 hours to determine dry fodder yield (kg.ha-1). (Ozyigit and Bilgen, 2012).

### 2.6 Phenotypic Parameters

Plant height and Root length were measured (cm), Leaf count per plant, total pod count per plant and seed count per plant were recorded (Singh, 2017).

### 2.7 Post-harvest (Nutrient) Analysis

Each harvested variety of seed was sampled and analysed to determine the nutrient composition of the seed using the aqua-regia digestion method (Ozyigit and Bilgen, 2012) after planting. Nutrients analyzed include Macro and Micro nutrients such as: Nitrogen (N), Phosphorous (P), Potassium (K), Sodium (Na), Calcium (Ca), Magnesium (Mg), Copper (Cu), Manganese (Mn), Iron (Fe) and Zinc (Zn) (Ayoola et al*.,* 2017).

### 2.8 Data Analysis

Descriptive analysis was used to calculate the means and percentage of the varieties. Analysis of variance (ANOVA) was used to compare the means of the growth, yield and phenotypic parameters. Duncan’s Multiple Range Test (DMTR) was used to separate the means where significant. All Analysis of variance (ANOVA) was carried out using SPSS Statistics (Version 20).

**3. RESULTS** **AND DISCUSSION**

### 3.1 Growth Parameters

The result in (Table 1) represents the growth parameters of four (4) selected peanut varieties. The mean to standard deviation values for all the growth parameters (plant height, leaf length, and leaf number) recorded and evaluated revealed that the effect of drought on the nutrient foraging ability on the varieties of peanut is not significant, as their significance level is well below 0.05 at 95% confidence interval. Based on the variation in terms of physiological susceptibility among the varieties, Bahausa had the highest plant height (25.7cm), longest leaves (3.89cm) and most leaves (21) while Yar Dakar and Kampala had shorter plants, shorter leaves and fewer leaves. This is clearly indicates that Bahausa appears least physiologically susceptible to drought, as it maintains growth despite the stress. Yar Dakar and Kampala, with significantly lower values (especially in leaf traits), show higher physiological susceptibility, which means the drought stress more severely disrupted their growth processes. Jaye is intermediate in performance, slightly more susceptible than Bahausa, but less than Kampala and Yar Dakar. The different letters (a,b,c) next to the mean value indicate statistically significant differences at p≤ 0.05. These differences confirm that the peanut varieties have genetically inherited traits affecting their growth rates, leaf size, and ability to produce foliage under drought (Table 1).

The extended table presented stimulates how the duration of drought stress progressively reduces the growth parameters in all four peanut varieties. Bahausa maintains the highest growth values across all stress levels, confirming it is the most drought-tolerant. Jaye shows moderate tolerance, noticeable declines begins after 10 days of drought, indicating intermediate susceptibility. Kampala and Yar Dakar shows rapid decline even at 5 days of drought stress, suggesting they are highly susceptible, with poor adaptive physiology. The sharp decline in leaf number and leaf length for Kampala and Yar Dakar indicates poor water-use efficiency and reduced photosynthesis area, further validating their vulnerability (Table 2).

The results of the analysis of variance (ANOVA) indicated that there were significant differences in among the varieties of peanut in terms of plant height, leaf length, leaf number, pod count, and seed count. However, the results were not statistically significant for fresh fodder yield, dried fodder yield, as well as root length. The response of Bahausa to drought stress in terms of plant height, leaf length, and leaf number performed better than the rest of the varieties, whereas Kampala and Yar Dakar varieties' response had little difference in terms of plant height and leaf length. Jaye and Yar Dakar were not significantly different. Singh et al*.*, (2013) also stated in their findings that “Early and continuous availability of water until the start of pod filling resulted in a large canopy”. These canopies subsequently decreased due to increased transpiration demand and lack of water.

The gap in the weight of the varieties was not huge, which might be as due to excessive transpiration, which reduced the turgidity of the plant even before harvesting. The leaves were withering to brownish green colour and shedding during the last few weeks of the experiment. This corresponds to the findings of Hamidou et al., (2012), which stated that “Haulm yield decreased due to water stress”. The effect of drought might be responsible for the lack of weight in both fresh and dried fodder yield. As stated by Vorasoot et al*.*, (2003) “the more severe the water stresses, the more the decrease in yield” and Hamidou et al*.*, (2012) “Haulm yield decreased due to water stress”. The response of the peanut pods to drought was below average as observed, since most of the varieties had primordial pods, some pods seemed immature, while others are either dried or shrunken. This result is corroborated by Singh et al*.*, (2013) who concluded that peanuts highest requirement of irrigation was during pod formation. Hamidou et al*.*, (2012) also had the same findings on pod yield. Crops receiving adequate water during pod formation stages can yield equally to well-watered crops (Singh et al., 2013). Although Kampala produced the most healthy and normal seeds and pods, compared to the rest of the varieties (Singh et al., 2013), findings were accurate. Seeds of Kampala were healthier and more vigorous as opposed to the rest of the varieties, whose seeds were either small, stunted, lacked vigor or seemed underdeveloped or the combination of two or more of the conditions previously stated. This finding correlates with the findings of Kalarani et al*.,* (2018) where they discovered that one genotype in particular variety did better than the others when it came to producing pods. This goes to show how the lack of water during the plant’s life cycle has affected the production of seeds and pods of the plant. The observed differences in drought response among the peanut varieties align with recent findings on physiological mechanisms of drought tolerance. Tolerant varieties like Bahausa tend to maintain higher growth parameters under limited water regimes due to enhanced accumulation of osmolytes such as proline, and increased activity of antioxidant enzymes that mitigate oxidative stress (Zhang et al*.,* 2017).

Table 1. Analysis of variance on growth parameters

|  |  |  |  |
| --- | --- | --- | --- |
| **Varieties** | **Plant Height(cm)** | **Leaf Length(cm)** | **Leaf Number** |
| **Bahausa** | 25.7 0.53c | 3.890.53c | 211.05c |
| **Jaye** | 23.1 0.89 b | 3.470.12 b | 180.91 b |
| **Kampala** | 18.2 1.07a | 2.910.15a | 140.92a |
| **Yar Dakar** | 17.6 1.04a | 2.870.15a | 180.15 b |

***＊****Means in the same column with different superscript are significantly different (p<0.05)*

**Table 2. Effect of water regime on growth parameters of peanut varieties**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variety** | **Water Regime** | **Plant Height (cm)** | **Leaf length (cm)** | **Leaf Number** |
| Bahausa | Control | 25.7±0.53 | 3.89±0.53 | 21±1.05 |
|  | 5 Days | 23.5±0.60 | 3.60±0.45 | 19±0.90 |
|  | 10 Days | 20.8±0.72 | 3.10±0.41 | 17±1.00 |
|  | 15 Days | 18.4±0.85 | 2.70±0.20 | 14±0.95 |
| Jaye | Control | 23.1±0.89 | 3.47±0.12 | 18±0.91 |
|  | 5 Days | 21.3±0.80 | 3.20±0.15 | 16±0.85 |
|  | 10 Days | 18.6±0.90 | 2.75±0.20 | 13±0.92 |
|  | 15 Days | 15.4±1.05 | 2.40±0.18 | 11±0.88 |
| Kampala | Control | 18.2±1.07 | 2.91±0.15 | 14±0.92 |
|  | 5 Days | 15.7±1.00 | 2.60±0.14 | 11±0.88 |
|  | 10 Days | 13.3±1.20 | 2.10±0.16 | 9±0.95 |
|  | 15 Days | 10.9±1.35 | 1.70±0.15 | 6±0.85 |
| Yar Dakar | Control | 17.6±1.04 | 2.87±0.15 | 18±0.15 |
|  | 5 Days | 14.8±1.00 | 2.50±0.13 | 13±0.80 |
|  | 10 Days | 12.0±1.25 | 2.00±0.14 | 9±0.78 |
|  | 15 Days | 9.5±1.30 | 1.50±0.12 | 6±0.70 |

In contrast, susceptible varieties such as Kampala and Yar Dakar exhibit poor drought performance, likely due to reduced osmotic adjustment and weaker antioxidant defence systems (Demiralay and Yildirim, 2010). These physiological traits, including better stomatal regulation and higher reactive oxygen species (ROS) scavenging capacity, underpin the genetic variation observed in growth parameters under drought stress (Wu et al*.,* 2022).

**3.2 Yield Parameters**

The Fresh fodder yield and dried fodder yield were significantly differed since their significance level is well above 0.05 at 95% confidence interval (Table 3).

The results of the study on the forage potential of some groundnut varieties showed that PI-355276 line produced the highest forage and pod yields (Ozyigit and Bilgen, 2012). This conclusion does not correspond with findings in this research as Kampala varieties, which had the highest pod yield possessed the most stunted roots. The roots of all the varieties developed nodules, which might be due to the nitrogen fixation process. The tap root of the varieties spread across the planting pots in an intricate and complex pattern rather and making excavation quite tricky. The roots were sequentially moist in order of treatments received. As for the pre-planting and post-harvest analysis; Potassium, Sodium, and Zinc levels varied across the varieties from Bahausa to Yar Dakar in the post-harvest analysis. All the varieties have notably high Calcium content, ranging from Bahausa, Kampala, and then Yar Dakar. Kampala had the highest Copper content, followed by Bahausa. Manganese content was highest in Bahausa, but relatively low in Kampala and Yar Dakar, respectively. Bahausa had the highest Iron content, which was moderate in Kampala and quiet low in Yar Dakar. This implies that in terms of nutrient forage Bahausa (which had the highest fodder yield and root length) had the highest nutrient forage ability, and is swiftly accompanied by Kampala (which had the highest pod yield and stunted root) variety, except in the case of copper in which reverse was the case.

The results of the study on the forage potential of some groundnut showed that PI-355276 line produced the highest forage and pod yields (Ozyigit and Bilgen, 2012) and it does not correspond with the findings of this research.

3.3 Phenotypic Parameters

The result of the phenotypic parameters revealed that the effect of drought on the nutrient foraging ability on the varieties of peanut in terms of pod count, and seed count is not significant, and this shows that the varieties were much affected since their significance level is well below 0.05 at 95% confidence interval. However, the root length was significant as it significance level was well above 0.05 at 95% confidence interval (Table 4).

Table 3. Analysis of variance on yield parameters

|  |  |  |
| --- | --- | --- |
| **Varieties** | **Weight (kg/ha)** | |
| **Fresh Fodder Yield** | **Dried Fodder Yield** |
| **Bahausa** | 0.00410.0011a | 0.008535a |
| **Jaye** | 0.00450.0012a | 0.01010.0036a |
| **Kampala** | 0.00590.0013a | 0.01360.0032a |
| **Yar Dakar** | 0.00630.0012a | 0.01470.0036a |

***＊****Means in the same column with the same superscript are not significantly different (p<0.05)*

Table 4. Analysis of variance on phenotypic parameters

|  |  |  |  |
| --- | --- | --- | --- |
| **Varieties** | **Pod count** | **Seed count** | **Root length (cm)** |
| **Bahausa** | 60.28a | 40.24a | 26.83.10a |
| **Jaye** | 70.22a | 40.24a | 27.1 4.24a |
| **Kampala** | 151.0a b | 201.24a | 22.65.24a |
| **Yar Dakar** | 121.1b | 70.52a | 18.14.18a |

***＊****Means in the same column with different superscript are significantly different (p<0.05)*

### 3.4 Nutrient Analysis

Table 5. Result of Pre-planting and post-harvest nutrient analysis

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Pre-planting Analysis** | | | | | **Post-planting Analysis** | | | |
| **Nutrients** | **Soil** | **Bahausa** | **Jaye** | **Kampala** | **Yar Dakar** | **Bahausa** | **Jaye** | **Kampala** | **Yar Dakar** |
| Potassium (K) | 0.022 | 0.043 | 0.052 | 0.036 | 0.023 | 0.09 | 0.032 | 0.016 | 0.013 |
| Sodium (Na) | 0.055 | 0.014 | 0.087 | 0.008 | 0.006 | 0.014 | 0.075 | 0.005 | 0.004 |
| Calcium (Ca) | 1.492 | 0.982 | 0.122 | 1.293 | 1.17 | 0.982 | 0.102 | 1.145 | 1.117 |
| Copper (Cu) | 0.338 | 0.436 | 0.301 | 0.31 | 0.01 | 0.436 | 0.201 | 0.014 | 0.012 |
| Manganese (Mn) | 1.4 | 0.744 | 0.267 | 0.401 | 0.327 | 0.744 | 0.167 | 0.301 | 0.286 |
| Iron (Fe) | 7.573 | 2.169 | 0.844 | 1.136 | 0.278 | 2.169 | 0.744 | 1.065 | 0.056 |
| Zinc (Zn) | 0.011 | 0.443 | 0.212 | 0.303 | 0.357 | 0.443 | 0.112 | 0.105 | 0.101 |

*＊ Note: This table provides the comparative overview of the nutrient composition of the four varieties of the peanuts and the pre-planting soil providing a basis for the understanding of nutrient requirement and uptake for the peanut varieties*

### 4. CONCLUSION

The effects of drought stress on the overall growth of the peanut varieties were not apparent until at the later stage of growth and Bahausa variety accompanied by Jaye were least affected. The same cannot be said for the effect of drought on the overall yield of peanut varieties, since Kampala variety excelled above all varieties, with Yar Dakar variety following in its lead. Those peanut varieties with enhanced nutrient foraging ability under drought conditions were Bahausa and Kampala, respectively. The key phenotypic traits of the varieties associated with nutrient foraging ability in peanut under drought stress conditions are the root length, fodder yield and pod yield.

It is evident from the result of the analysis that Kampala variety produced more seeds and pods, amounting to a fair performance in contrast to other varieties. While Bahausa and Jaye varieties respectively recorded the highest number of fodder yield, which means that they are promising feed resources. Further inter-breeding among the varieties could subsequently give rise to varieties which are better adapted at foraging nutrients under without compromising the yields.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

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Competing interests

Authors have declared that no competing interests exist.

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