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# EFFECT OF SOWING DATE ON GRAIN QUALITY OF SORGHUM (*Sorghum bicolor* L. Moench) IN THE NILE CORRIDOR AGROECOLOGICAL ZONE OF SOUTH SUDAN

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**ABSTRACT**

Sorghum (*Sorghum bicolor* (L.) Moench) is a staple food for a considerable number of people in Africa and Asia. However, poor grain quality is a major concern for the rural communities who depend mainly on sorghum grain for food. Protein, minerals and tannins are important indicators of grain quality. Their quantity is critical in choice of variety to grow for food. An experiment was carried out in a randomised complete block design by sowing 5 sorghum varieties on 18$^{th}$ June, 29$^{th}$ June and 10$^{th}$ July 2015 - in Bor and Arek South Sudan. The objective of the study was to determine the effect of sowing date on protein, tannins, iron and zinc content in sorghum. Grain samples of five sorghum varieties sown on various dates were collected and analysed at Kenya Agricultural and Livestock Research Organization (KALRO) Njoro. Protein content was determined using method 44 from Association of American Cereal Chemists. Tannins were determined using the Improved Vanillin- Hydrochloric Acid Assay (IVHAA) while minerals; iron and zinc were determined using Atomic Absorption Spectrophotometry. Significant site by variety by sowing date interactions at $P < 0.05$ level of probability were obtained for protein, iron and zinc content of sorghum varieties but not for tannins. Highest protein content of 11.55 per cent was achieved when varieties were sown on 29$^{th}$ June in Bor. Protein of 11.40 per cent was obtained when varieties were sown on 18$^{th}$ June in Arek. At Bor, Beer, Dhet and Seredo varieties; 12.76, 11.0 and 10.64 per cent protein respectively were recorded. At Arek, Beer Seredo and Dhet attained 12.03, 10.92 and 10.60 per cent protein content respectively. Sorghum varieties sown on 18$^{th}$ June had less tannins of 1.19 mgml$^{-1}$in Bor and 1.09 mgml$^{-1}$in Arek while varieties sown on 10$^{th}$ July had highest tannins 1.49 mgml$^{-1}$ in Bor and 1.40 mgml$^{-1}$ in Arek. Amongst the varieties, Seredo and Agany contained high tannins while Beer and Dhet contained less tannins. Iron and zinc content in sorghum showed higher values for 29$^{th}$ June sowing date both in Bor and Arek. The study showed that Beer and Dhet varieties have good quality grains that can be used to improve human nutrition, hence can be recommended to sorghum farmers in Bor and Arek region.

**Key words:** Sorghum, Date, Grain quality, Cluster, Tannins, Protein, Iron, Zinc



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## INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is a neglected crop but of importance, particularly in the arid and semi-arid lands (ASALs), where many lives depend on the crop as a major source of food [1]. Sorghum has the advantage of performing relatively well under stress conditions such as drought and floods [2]. This provides an opportunity to increase production and yield of sorghum where other crops may fail. Food insecurity can be better addressed by increasing sorghum production in marginal areas of sub-Saharan Africa where majority of the population are starving or malnourished [3].

Protein, minerals and tannins contents are important indicators of grain quality in sorghum and other cereals [4]. An ideal sorghum grain for consumption should provide adequate protein, iron and zinc while containing less anti-nutritional compounds [5]. Sorghum quality parameters include; starch content, ash content, protein content and mineral contents and the quantity of anti-nutritional tannins and phytic acid [6].

Low protein in sorghum has been a persistent problem and subject of study since 1970s [7]. Protein in sorghum was reported within the range of 5-16 per cent both in food and forage types [7, 8]. It is recognized that protein in sorghum provides essential amino acids including lysine, histidine, arginine, glycine, threonine, aspartic acid and valine. However, presence and quantity of anti-nutritional compounds such as tannins, phytic acid and saponins affect protein digestibility as they precipitate proteins. Although gluten-free sorghum meal has been prescribed for people suffering from celiac disease, proteins remain an important source of energy in human and animal diets [8].

Evaluation of sorghum genotypes and selection for high protein can contribute to reduced malnutrition among sorghum consumers. Breeding work focussing on increasing total protein in sorghum hybrids has helped but with little success [9].

Phenolic tannin is the most abundant anti–nutritional compound in sorghum. Sorghum contains tannins of varying amount depending on genotypes [10]. Tannins are naturally occurring water-soluble high molecular weight polyphenols that bind on to and precipitate proteins in aqueous solutions [11]. Tannins can be categorized into condensed tannins (CTs) and hydrolysable tannins (HTs), Condensed tannins are the form of tannins found in the testa layer of the pericarp [12]. Their presence in sorghum is believed to give sorghum characteristic astringent taste and reduce biological value especially when consumed by mono-gastric animals including humans [13]. Contrastingly, consumption of sorghum containing hydrolysable tannins has health benefits due to antioxidant property of tannins, which help fight toxins and reduce chances of acquiring various types of cancers. Besides health benefit in grain sorghum, tannins content is known to reduce the risk of birds' damage on field-grown sorghum [14].

Deficiency of minerals in plants results into retarded growth and may cause plant death [15]. Minerals such as calcium, Iron, Sulphur and Zinc form component of essential amino acids found in seeds and tubers. Since humans derive their nutritional needs

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from plants, adequate content of minerals in consumable plants is important. Iron is the main component of haemoglobin, the main constituent of blood. Consumption of adequate iron-containing sorghum meals prevents anaemia and reduces chances of acquiring diseases [16]. Zinc, on the other hand, enhances the nervous system and its functions [17]. Therefore, micronutrient enhanced sorghum variety that provides adequate iron and zinc would improve health and performance of sorghum consumers.

Sowing date has been observed to indirectly affect grain quality in sorghum, wheat, maize and oats [18, 19, 20, 21]. Early sowing, vis-a-vis late sowing affects grain yield and composition. Early sowing provides longer growing period and efficient grain filing, while late sowing was found to shorten maize cycle leading to low yield and poor quality grain in maize [22]. Currently, limited information is available on the effect of sowing dates on sorghum quality parameters. The only available study on effect of sowing date on sorghum quality done by Ratnavathi *et al*. [23] found out that cane yield, per cent brix of stem juice, per cent juice extractability, per cent total soluble sugars and reducing sugars in the stem juice of sweet sorghum were reduced at late planting date. Since sorghum grain quality is nutritionally important to consumers, there is a need to address the effect of sowing date on sorghum grain quality. Identification of sorghum varieties with high protein, iron and zinc but less tannin is an indicator of good quality sorghum variety desirable to consumers.

## MATERIALS AND METHODS

### Site description

The study was carried out during 2015 cropping season in Bor (6.21° N and 31.56° E) and Arek (6.28° N and 31.45° E), which are 20 kilometres apart and found at east side of the White Nile in South Sudan. The area lies on a flat lowland susceptible to floods from the rain water due to poor drainage. The soil is deep, dark grey, very firm, cracking clayey loam (Pellic Vertisols) with pH range of 6.5-7.5. The weather is mostly warm throughout the year with mean daily temperatures ranging from 25-40 $^{o}$ C. The area is characterised by one growing season of 130 – 150 days with summer rains from May – October [24]. Bor is located at an altitude of 407 metres above sea level (m.a.s.l.) while Arek is at 415 m.a.s.l. A 5-year mean annual rainfall for Bor and Arek ranged between 400 and 800 mm.

Soil samples from Bor and Arek were tested for soil nitrogen, phosphorus, per cent carbon and pH before sowing and results are presented in Table 6. Rainfall data were also recorded at Bor and Arek during the entire season and the data are presented in Table 7.

### Experimental procedure and data collection

Five sorghum varieties namely: Beer, Akuorachot, Dhet, Agany and Seredo were sown on 18$^{th}$ June, 29$^{th}$ June and 10$^{th}$ July sowing dates as these represent intervals for farmers' sowing dates. A 2 × 3 × 5 factorial randomised complete block design with three replications was used. Spacing of 0.6 by 0.5 metres of inter and intra row was measured to achieve a plant population of 33,334 plants ha$^{-}$1. Compound fertilizer N: P: K: fortified formulation with micro nutrients: Fe: Zn fertilizer was applied in Arek

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supplying 60 kg $ha^{-1}$ N and 70 kg $ha^{-1}$ N in Bor. Phosphorus was applied at the rate of 10 and 15 kg $ha^{-1}$ at Arek and Bor respectively. Micro nutrients, iron and zinc were applied at packaging formulation at 5 Kg ha $^{-1}$ in Bor and Arek. At 50% flowering, midge attack was noted and Thunder (Bayer Crop Science AG, Germany) with active ingredients (Imidacloprid + Beta-cyfluthrin) was applied at formulation of 25ml/20 litres on 731 $m^2$ area.

At maturity, 9 sorghum plants were harvested from the inner rows per plot dried and threshed and yield data recorded. The grains were cleaned to remove hulls and sun-dried to constant moisture content; this was ascertained by observing no more change in the mass of the grain after 4 days of sun drying. A total of 15 samples (3 sowing dates for 5 varieties) were analysed at Kenya Agricultural and Livestock Research Organization (KALRO) Njoro's cereals laboratory to determine levels of protein, tannins, iron and zinc contents of sorghum grains. Thirty grams of grain per sample was ground into a fine flour using a special iron- and zinc- free chromium ball mill (Retsch mill model, MM 400) to avoid contamination. The flour was passed through a 1 mm sieve to obtain easily digestible flour for analyses.

Nitrogen content was determined using the KJEHDAL method of nitrogen determination specified in Association of American Cereal Chemists Method 44-13 vol. 2 [25]. Total tannins were determined using Improved Vanillin – Hydrochloric Acid Assay process taken at 500 nm [11, 14]. The condensed tannins were assessed as catechins equivalent in $mgml^{-1}$ [26]. Catechins equivalence (CE) was determined according to linear equation obtained from standard graph.

$$\text{Catechins}\left(\frac{\text{mg}}{\text{ml}}\right)\text{x} = \text{y} - \frac{0.0039}{0.0706}$$

Where y = Absorbance (nm)
X = Catechins ($mgml^{-1}$).

Iron and zinc content were determined using Atomic Absorption Spectrophotometry. After digestion, samples were analysed for iron and zinc metals by measuring absorbance at 248.33 nm for iron and 213.86 nm for zinc using an Atomic Absorption Spectrophotometer, (Shimadzu Model AA-6300, Tokyo-Japan).

**Data Analysis**
The biochemical data were analysed using SAS Version 9.0 using PROC GLM procedure to generate analysis of Variance (ANOVA) and determine significance at $P < 0.05$ level of probability [27]. Whenever there was significance, means for the biochemical traits were presented as mean plus standard deviation $\pm$ (SD).

Dendograms were derived using the software Minitab Version 17 using distance matrix of unpaired group mean linkage cluster analysis (UPGMA) to compare biochemical similarities for the sowing dates and within sorghum varieties [28].

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## RESULTS

### Effect of sowing date on grain quality of five sorghum varieties

Mean squares for the protein, tannins iron and zinc are presented in an ANOVA format (Table 1). Date of sowing did not affect protein content of sorghum varieties. However, grain protein varied with the variety, site and sowing date interactions (Table 1). Grain protein ranged from 8.42 – 15.10 with a mean of 10.77 among the varieties.

Sorghum varieties were statistically different at $P < 0.01$. Beer variety outperformed other varieties with the highest protein content of 12.40 per cent. Dhet ranked second to Beer followed by Seredo while Akuorachot and Agany varieties were lower in protein content.

Site of sowing was not independently significant but had a significant joint interaction site-date and site-variety date interactions which were all significant at $P < 0.05$ level of probability at Bor and Arek sites. A strong coefficient of determination $R^2 = 0.86$ was measured for the protein content amongst sorghum varieties (Table 1).

Variety-sowing date interaction was significant for tannin content (Table 1). Among the three sowing dates, $10^{th}$ July sowing date gave higher tannin content than $29^{th}$ and $18^{th}$ June in a descending order. It was apparent that tannins accumulate with delayed-date of sowing (Table 3). At Bor, Dhet variety sown on $29^{th}$ June had the lowest tannin content (0.71) $mgm^{-1}$ while Seredo sown on $10^{th}$ July gave the highest tannin content 3.28 $mgml^{-1}$. At Arek, Beer variety sown on $18^{th}$ and $29^{th}$ June recorded lower tannin content of 0.56 $mgm^{-1}$, while Seredo sown on $10^{th}$ July gave the highest tannin content of 3.08 $mgm^{-1}$.

It was observed that tannins were significantly higher for plants grown in Bor compared to when sown in Arek (Table 3). It was noted that Seredo has the highest tannins, Agany and Akuorachot has low tannins while Beer and Dhet have the lowest tannins.

Iron content of sorghum grains were significant at $P < 0.05$ level of probability for variety, site and date of sowing interactions (Table 4.1). Dates of sowing affected grain iron content of sorghum varieties. The $29^{th}$ June date of sowing achieved the highest grain zinc content followed by $10^{th}$ July while the $18^{th}$ June sowing resulted in the lowest grain iron content (Table 4). Highest iron content was found in Seredo and Dhet varieties while the lowest was recorded in Akuorachot and Beer varieties.

Grain zinc content was significant at $P < 0.05$ and 0.01 levels of significance for all the model components except the replications (Table 1). The zinc content for the three dates of sowing were significantly different at $P < 0.05$ level of probability. Grain zinc content was observed to increase with the delay in date of sowing with the lowest zinc recorded for the $18^{th}$ June date of sowing (Table 5). Seredo and Agany achieved the highest zinc content while Beer and Akuorachot got the lowest zinc content.

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**Biochemical mean linkage cluster analysis**

A distance matrix was used to construct cluster dendograms using Unpaired Group Mean Linkage Cluster Analysis (UPGMA). Three sorghum sowing dates were compared and clustered into two distinct groups (Figure 1). The first group consists of 29$^{th}$ June and 10$^{th}$ July sowing dates which were clustered in one group. The closeness of late sowing was exhibited by 37% similarity level separated by distance matrix of 2.36 between 29$^{th}$ June and 10$^{th}$ July sowing dates. To expectation, 18$^{th}$ June date of sowing was distinct from the other sowing dates showing a maximum distance of 3.73 from the first cluster group.

Sorghum varieties were segregated into 4 cluster groups which were linked to genotypic similarities and characteristics (Figure 2). The first group was Dhet and Agany, which had close biochemical similarity level of 63% and a distance matrix of 1.78 forming a very tight cluster group. Beer and Akuorachot also formed a cluster group with similarity level of 42% and formed a distance level of 2.76 within the two landrace varieties. The third group cluster had four varieties, Dhet, Akuorachot, Beer and Agany, which were diverse and showed similarity level of only 39% with group distance level of 2.92 within the sorghum accessions. The last cluster consists of Seredo with distinct characteristics from all other sorghum genotypes as shown by closeness from 0 similarity level.

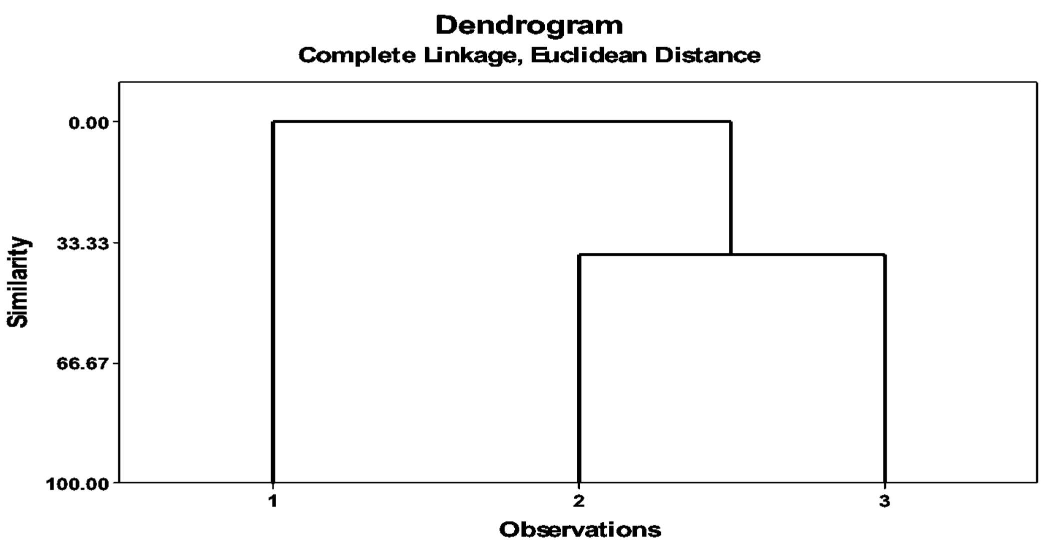


**Figure 1: Dendogram showing mean similarity levels in yield, protein, tannins, iron and zinc content of sorghum as affected by dates of sowing. (1, 2 and 3 represent sowing dates; 18$^{th}$ June, 29$^{th}$ June and 10$^{th}$ July respectively)**

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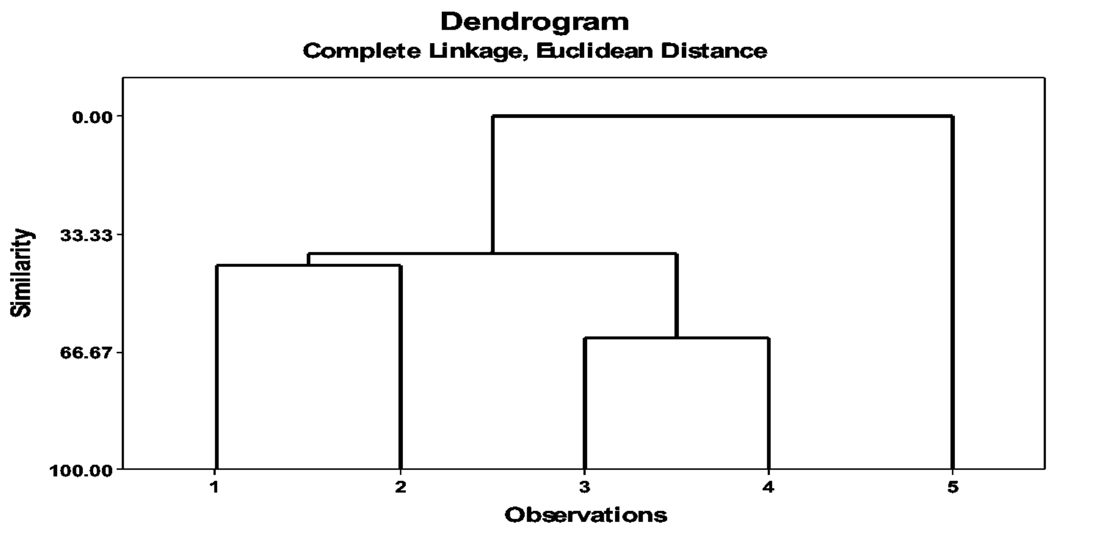


**Figure 2: Dendogram showing mean similarity levels in yield, protein, tannins, iron and zinc content of sorghum varieties. (1, 2, 3, 4 and 5 represents sorghum varieties namely; Beer Akuorachot, Dhet, Agany and Seredo respectively)**

## DISCUSSION

The protein content in sorghum was affected by genotype, location and sowing date interaction. This is in line with the findings of Trikoesoemaningtyas *et al.* [29] that showed genotype and environment are responsible for variation in protein content in Indonesian sorghums. Pal *et al.* [30] observed that sorghum varieties have varying nitrogen use efficiencies.

Total nitrogen varied with the variety and this can be related to the genotypic differences as the gene make up of variety affects the ability for nitrogen's uptake in the soil which may result in higher protein in some varieties compared to others. This confirms the finding of Wylie who showed that protein in grain depends on the nitrogen uptake of a variety [31]. It was observed that the Beer compared to other varieties was higher in protein content probably due to better nitrogen use efficiency.

Site differences were revealed as higher total protein for varieties sown in Arek compared to those planted in Bor. This can be further explained by differences in nitrogen distribution despite equal application of fertilizer. The soil properties might have affected nitrogen infiltration and leaching which might have caused significant difference in nitrogen availability and uptake in sorghum.

Another possibility is the fact that moisture is critical in nitrogen dissolution. Arek site received higher precipitation and was associated with low protein level in sorghum. Some soils hold water longer than others; For instance, loam soils have high water holding capacity due to fine size and compactness of the soil aggregates which affects the level of nitrogen leached or taken up in plant roots [18].

The date of sowing although not directly reflected in the differences in protein content showed that late sowing was associated with small sized grain with high protein content. In contrast, early sowing of cereals results in large sized grain with low protein content [19]. These results corroborate the findings of Jehangir *et al.* who also found increase in protein content in oats in late sowing compared to early sowing [21]. Although previous research found decrease of grain quality in late sown maize, means for protein content in late sown maize were higher than in early sown maize [20, 22].

Tannin content of sorghum varieties was affected by variety and date of sowing; in low tannin containing Beer and Dhet varieties, late sowing resulted in increased tannin content but remain low in early sowing dates. In high tannin containing varieties Seredo and Akuorachot, early sowing resulted in low tannin content but is elevated in late sowing dates. This finding agreed with Serrano *et al.* [32] who showed that late sowing was associated with high tannin in sorghum.

Seredo, which is a dull red variety contained highest tannin followed by Agany, while light-coloured Beer showed lowest amount of tannin. Akuorachot which is a milk-white variety contained significant amount of tannin. When the grain was milled, it tarnished into dark coloured flour suggesting that tannin might exist in the endosperm of the grain. Dhet on the other hand is purplish-brown but had lower tannin content than Agany which is creamish yellow. These results indicate that tannin content in sorghums does not necessarily correspond to seed colour but instead is determined by a gene known as *tannin1* allele in sorghum [33]. Most variation in tannin content of sorghums varieties was linked to the genotypes. Since there are no records on the suitable tannin content in edible sorghums, there is a need to establish acceptable standard of tannin content in sorghum varieties.

Site of sowing is associated with the change in tannins in a variety as levels of plant stress increase [10]. Polyphenols and secondary metabolites in general are known as defence chemicals and are produced in response to stress. These compounds include; terpenoids, alkaloids and tannins whose production is determined by level of stress in plants. Some of the stress factors which trigger the production of secondary metabolites include drought, mineral deficiency and physical injury [34]. Initially, Arek had better structured fairly higher nutrients and higher moisture content than Bor which was low in all of the aforementioned components. These differences are more likely to have caused stress in sorghums sown at Bor resulting in increased levels of tannin in varieties sown in Bor compared to those sown at Arek.

Seredo and Agany contained more tannins than Beer and Dhet varieties probably due to environmental stress that gave varying tannins in the same variety sown at different sites. The differences in tannin content were sensitive as variation was detected even within the replicates. This variation in tannin levels may be due to change in soil properties and topography which influences nutrients and water availability [34].

Iron and zinc minerals exhibited similar response as all were affected by site, variety and date interactions. The result corroborates the findings of Ashok *et al*. [35] who concluded that mineral availability and uptake depend on genes and growth

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environment. Site differences were implicated due to soil properties, environmental factors as well as genotypic differences, which all contribute to variations in mineral content in sorghum.

Since soil temperature decreases as season advances, early sowing is often associated with warmer soil compared to late sowing. Due to this effect of soil temperature, 29$^{th}$ June and 10$^{th}$ July sowing dates recorded high Fe and Zn compared to 18$^{th}$ July in Bor and Arek. This finding is in agreement with Horrocks and Yang [36] who reported decrease in Fe, Zn and Mn when sorghum was sown under warm soil conditions. Soil temperature affects Fe, Zn uptake in sorghum as Raju found higher potassium uptake when sorghum was sown at soil temperature of 32 $^{o}$ compared to when sown at low temperature of 15 $^{o}$ C [37,38]. Warm soil between 25 - 30 $^{o}$ C was found to increase uptake of N, P, K, Ca, Fe and Zn and increased biomass compared to 15 - 20 $^{o}$ C soil temperature in sorghum [39]. Therefore, late sowing was favourable for nutrient uptake compared to early sowing.

Soil properties such as cation exchange capacity (CEC) supports mineral uptake during active transport of soil nutrients. Soil with greater CEC usually enhances rapid nutrient uptake compared to soil with low CEC. Thus, clayey loam soils allow higher mineral uptake compared to less porous clayey soils. These factors might have contributed to variability in grain Fe and Zn of sorghum varieties [35].

Genotypic characteristics such as root length, root numbers and root density were not evaluated but might have affected sorghum ability to absorb minerals. Velu *et al*. [39] linked variation in zinc and iron uptake to genotypic differences in millets. All these factors contributed to variation in iron and zinc content of sorghum grains.

**Biochemical mean linkage analysis**

Mean biochemical cluster association may be used to identify genetic closeness as well as genetic drifts of related genotypes. Cluster analysis for sowing dates grouped 29$^{th}$ June and 10$^{th}$ July sowing dates into a similarity cluster group. The two dates had higher biochemical content than 18$^{th}$ June planting date indicating efficient photosynthesis, better moisture and mineral uptake between these varieties. The biochemical closeness in tannins accumulation with delayed sowing formed the basis of biochemical cluster between 29$^{th}$ June and 10$^{th}$ July sowing dates. This increase in tannin content was associated with late sowing and increase in stress level from 18$^{th}$ June to 10$^{th}$ July sowing dates.

Biochemical traits association clustered Dhet and Agany as biochemically close to each other. Despite high minerals content both in Dhet and Agany varieties, Dhet had more protein and least tannins while Agany had more tannins and less protein content. This may be used to place Dhet variety above Agany on recommended varieties.

Akuorachot and Beer landrace varieties were closely related based on mean + SD biochemical contents. Both varieties are related in total protein and minerals content but differ in tannins levels as Beer had no tannins but Akuorachot contained significant tannin content. Seredo was the only odd variety with high tannins, high minerals and moderate protein. However, biochemical closeness placed Seredo as a distinct genotype which does not relate to all the other varieties. Similar diversity has been reported in East African sorghums as varieties showed genetic diversity between open pollinated sorghums and hybrids [40]. Therefore, sorghum varieties tested in this study are distant relatives while Seredo hybrid is genetically isolated from all the other four varieties.

## CONCLUSION

The results of the present study indicate that variety, sowing date and growth environment have significant influence on grain quality of sorghum. Early sowing gave better sorghum grain quality than late sowing as indicated by high protein and mineral contents but low tannin levels. Varieties Dhet and Beer showed these desirable qualities and are being recommended. Under food insecurity conditions currently prevalent in South Sudan, all sorghum varieties used in this study could be improved through breeding to enhance their grain quality for human food.

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## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding this research.

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**Table 1: Means squares for the protein, tannins, iron and zinc contents of five sorghum varieties grown at three different sowing dates in Bor and Arek**

| Source | df | Protein | Tannins | Iron | Zinc |
|---|---|---|---|---|---|
| **Site** | 1 | 0.925 | 0.210** | 5884.16** | 694.55** |
| **Replicate** | 1 | 1.94 | 0.108* | 0.003 | 0.006 |
| **Variety** | 4 | 11.68** | 7.17** | 41380.66** | 2782.97** |
| **Site*Variety** | 4 | 0.312 | 0.015 | 2804.80** | 159.95** |
| **Date** | 2 | 0.702 | 0.479** | 1114.44** | 378.61** |
| **Site*Date** | 2 | 10.42** | 0.005 | 913.72** | 166.64** |
| **Variety*Date** | 8 | 2.835* | 0.101** | 468.86** | 65.26** |
| **Site*Variety*Date** | 8 | 2.539* | 0.033 | 650.73** | 184.42** |
| **Mean** | | 10.77 | 1.31 | 98.2 | 50.36 |
| **CV%** | | 7.6 | 8.3 | 1.03 | 3.21 |
| **$R^2$** | | 0.86 | 0.99 | 0.99 | 0.99 |

*Significant at $P < 0.05$, **Significant at $P < 0.01$
Key: $R^2$ - Coefficient of determination, CV% - Per cent Coefficient of variation

**Table 2: Means + SD for grain (%) protein of sorghum varieties as affected by site and date of sowing in Bor and Arek South Sudan**

| | | % Protein | | |
|---|---|---|---|---|
| **Site** | | **Bor** | | |
| **Sowing date** | **18th June** | **29th June** | **10th July** | |
| Varieties | | | | **Variety mean** |
| Beer | 10.87±0.32 | 14.45±0.66 | 12.98±0.31 | 12.76 |
| Akuorachot | 9.65±0.07 | 8.82±0.42 | 11.89±0.29 | 10.12 |
| Dhet | 9.50±0.14 | 13.29±0.74 | 10.22±0.59 | 11.00 |
| Agany | 9.9±0.42 | 9.95±0.97 | 10.00±0.56 | 9.95 |
| Seredo | 9.42±1.27 | 11.27±0.57 | 11.25±0.60 | 10.64 |
| Mean | 9.86 | 11.55 | 11.26 | 10.89 |
| | | **Arek** | | |
| Beer | 13.89 ± 1.79 | 11.56 ± 0.96 | 10.64 ± 1.47 | 12.03 |
| Akuorachot | 9.85 ± 0.36 | 10.12 ± 0.73 | 10.12 ± 0.73 | 10.03 |
| Dhet | 10.00 ± 0.56 | 10.88 ± 0.34 | 10.94 ± 1.05 | 10.6 |
| Agany | 11.43 ± 1.88 | 9.10 ± 0.71 | 9.05 ± 0.78 | 9.86 |
| Seredo | 11.82 ± 0.82 | 10.00 ± 0.56 | 10.94 ± 1.05 | 10.92 |
| Mean | 11.40 | 10.33 | 10.34 | 10.68 |

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**Table 3: Means +SD of tannins content in (mg/ml) for variety by date interactions for five sorghum varieties in Bor and Arek South Sudan**

| | | Tannins ($mgml^{-1}$) | | |
|---|---|---|---|---|
| **Sowing dates** | **18th June** | **29th June** | **10th July** | |
| **Site** | | **Bor** | | |
| **Varieties** | | | | **Variety mean** |
| Beer | 0.74 + 0.13 | 0.84 + 0.00 | 0.86 + 0.02 | 0.81 |
| Akuorachot | 1.1 + 0.15 | 1.1 + 0.08 | 1.13 + 0.02 | 1.11 |
| Dhet | 0.73 + 0.08 | 0.71 + 0.05 | 0.93 + 0.16 | 0.79 |
| Agany | 1.32 + 0.04 | 1.59 + 0.25 | 1.5 + 0.12 | 1.47 |
| Seredo | 2.08 + 0.14 | 2.85 + 0.03 | 3.08 + 0.08 | 2.67 |
| Mean | 1.19 | 1.41 | 1.49 | 1.37 |
| **Site** | | **Arek** | | |
| Beer | 0.56 +0.08 | 0.67 + 0.08 | 0.78 + 0.08 | 0.67 |
| Akuorachot | 0.81 + 0.14 | 1.10 + 0.09 | 1.11 + 0.14 | 1.00 |
| Dhet | 0.71 + 0.13 | 0.81 + 0.19 | 0.77 + 0.03 | 0.76 |
| Agany | 1.15 + 0.20 | 1.23 + 0.05 | 1.37 + 0.12 | 1.25 |
| Seredo | 2.25 + 0.16 | 2.48 + 0.25 | 2.96 + 0.06 | 2.56 |
| Mean | 1.09 | 1.26 | 1.40 | 1.24 |



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**Table 4: Mean +SD of grain iron content (ppm) of sorghum varieties grown across three different date of sowing in Bor and Arek South Sudan**

| | | **Iron (ppm)** | | |
|---|---|---|---|---|
| | | **Bor** | | |
| **Sowing date** | **18th June** | **29th June** | **10th July** | |
| **Varieties** | | | | **Variety Mean** |
| Beer | 61.5 ± 0.69 | 80.17 ± 0.48 | 61.15 ± 0.42 | 67.61 |
| Akuorachot | 21.1 ± 0.18 | 34.14 ± 0.02 | 25.07 ± 0.19 | 26.77 |
| Dhet | 190.06 ± 0.54 | 188.09 ± 0.17 | 174.16 ± 0.33 | 184.10 |
| Agany | 81.15 ± 0.86 | 84.17 ± 0.48 | 81.16 ± 0.93 | 82.16 |
| Seredo | 189.66 ± 0.64 | 173.88 ± 0.04 | 176.84 ± 1.77 | 180.13 |
| Mean | 108.69 | 112.09 | 103.68 | 108.15 |
| | | **Arek** | | |
| Beer | 60.98 ± 1.42 | 76.81 ± 0.00 | 32.24 ± 1.59 | 56.67 |
| Akuorachot | 28.88 ± 1.46 | 32.78 ± 0.62 | 38.26 ± 0.44 | 33.31 |
| Dhet | 81.69 ± 1.67 | 142.1 ± 0.53 | 114.87 ± 0.32 | 112.89 |
| Agany | 78.63 ± 0.91 | 80.51 ± 00 | 81.71 ± 1.69 | 80.28 |
| Seredo | 116.2 ± 1.56 | 166.99 ± 1.77 | 191.86 ± 1.49 | 158.35 |
| Mean | 73.27 | 99.84 | 91.79 | 88.30 |

Key: ppm – parts per million

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**Table 5: Mean +SD of grain zinc content (ppm) of sorghum varieties grown across three different sowing dates in Bor and Arek South Sudan**

| | | **Zinc (ppm)** | | |
|---|---|---|---|---|
| **Site** | | **Bor** | | |
| **Sowing date** | **18th June** | **29th June** | **10th July** | |
| **Varieties** | | | | **Variety mean** |
| Beer | 32.80 ± 0.74 | 67.57 ± 0.00 | 41.12 ± 0.52 | 47.16 |
| Akuorachot | 21.83 ± 0.28 | 33.14 ± 0.26 | 21.06 ± 0.81 | 25.34 |
| Dhet | 54.08 ± 0.02 | 62.98 ± 0.13 | 53.99 ± 1.39 | 57.02 |
| Agany | 67.16 ± 0.58 | 73.42 ± 0.68 | 67.41 ± 1.50 | 69.33 |
| Seredo | 64.03 ± 1.35 | 72.22 ± 1.44 | 76.33 ± 0.87 | 70.86 |
| Mean | 47.98 | 61.87 | 51.98 | 53.94 |
| | | **Arek** | | |
| Beer | 48.36 ± 1.27 | 37.84 ± 1.26 | 33.77 ± 0.63 | 39.99 |
| Akuorachot | 23.43 ± 1.27 | 25.88 ± 0.93 | 37.68 ± 0.21 | 28.99 |
| Dhet | 47.56 ± 1.43 | 64.62 ± 1.63 | 48.50 ± 1.51 | 53.56 |
| Agany | 44.00 ± 0.23 | 57.02 ± 1.71 | 60.55 ± 1.00 | 53.85 |
| Seredo | 64.16 ± 1.53 | 57.17 ± 1.97 | 53.81 ± 0.36 | 58.38 |
| Mean | 45.5 ± 1.15 | 48.51 ± 1.5 | 46.86 ± 0.74 | 46.95 |

Key: ppm – parts per million

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**Table 6: Initial soil characteristics at the study sites of Arek and Bor before planting**

| Sample | pH | Organic C % | Total N % | P mgkg$^{-1}$ | Remarks |
|---|---|---|---|---|---|
| **AREK** | 6.7 | 3.8 | 0.21 | **14.5** | |
| **BOR** | 6.4 | 3.5 | **0.19** | **9** | |
| **Critical Value** | $\geq$ 5.5 | $\geq$ 2.7 | $\geq$ 0.2 | $\geq$ 30 | |

**Table 7: Rainfall data recorded during 2015 growing season in Bor and Arek South Sudan**

| Mean Monthly Rainfall in Millimeters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Months** | **JAN** | **FEB** | **MAR** | **APR** | **MAY** | **JUN** | **JUL** | **AUG** | **SEP** | **OCT** | **NOV** | **DEC** | **Mean** |
| **AREK** | 0 | 0 | 8 | 16 | 32 | 26 | 48 | 106 | 66 | 66 | 24 | 16 | **392** |
| **BOR** | 0 | 0 | 4 | 12 | 36 | 20 | 42 | 84 | 56 | 52 | 18 | 12 | **324** |


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