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NUTRITIONAL PROFILES OF SORGHUM LANDRACES GROWN IN THE KARAMOJA SORGHUM-LIVESTOCK LIVELIHOOD ZONE OF UGANDA

PROFILS NUTRITIONNELS DE RACELANDES DE SORGHO CULTIVÉES DANS LA ZONE DE MOYENS DE SUBSISTANCE SORGHO-ÉLEVAGE DE KARAMOJA EN OUGANDA

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ABSTRACT

Sorghum (*Sorghum bicolor* (L.) Moench) is an important livelihood crop supporting 1.5 million people living in one of the world's destitute corners where 61% of the population live in absolute poverty, perpetuated by drought and heat leading to crop and livestock failure. This has resulted in many people being anaemic due to lack of adequate intake of zinc, iron and protein. However, the nutritional status of the commonly cultivated sorghum varieties in the zone is hardly known. The objective of this study was to establish the nutritional status of the commonly cultivated sorghum varieties in Karamoja Sorghum-Livestock Livelihood zone of Uganda. The profile analysis revealed high variation in tannins, crude proteins, iron and zinc content. All the varieties are good sources of iron (538.7-616.5 mg kg^{-1} dry matter) and zinc (44.19-48.21 mg kg^{-1} dry matter); while Kabir (0.13%) and Ekarengit (0.8%) contain low levels of tannins. Landraces Enyang (11.76%), Lokirion (12.56%) and Kaluman (10.64%) had high content of crude protein. There was no correlation between tannins with iron, zinc and crude protein; indicating that breeding for tannin content can be done without affecting other traits. Iron, zinc and crude protein were positively correlated, implying that they can be selected together for enhanced nutrient content.

Key Words: Protein, *Sorghum bicolor,* tannins, zinc

RÉSUMÉ

Le sorgho (*Sorghum bicolor* (L.) Moench) est une culture de subsistance essentielle qui fait vivre 1,5 million de personnes résidant dans l'une des régions les plus démunies du monde, où 61 % de la

population vit dans une pauvreté absolue, perpétuée par la sécheresse et la chaleur entraînant l'échec des cultures et de l'élevage. En conséquence, de nombreuses personnes souffrent d'anémie en raison d'un apport insuffisant en zinc, en fer et en protéines. Cependant, le statut nutritionnel des variétés de sorgho couramment cultivées dans cette zone est très peu connu. L'objectif de cette étude était d'établir le statut nutritionnel de ces variétés dans la zone de moyens de subsistance sorgho-élevage de Karamoja en Ouganda. L'analyse de profil a révélé une forte variabilité des teneurs en tannins, en protéines brutes, en fer et en zinc. Toutes les variétés constituent de bonnes sources de fer (538,7-616,5 mg kg^{-1} de matière sèche) et de zinc (44,19-48,21 mg kg^{-1} de matière sèche), tandis que Kabir (0,13 %) et Ekarengit (0,8 %) présentent de faibles teneurs en tannins. Les races locales Enyang (11,76 %), Lokirion (12,56 %) et Kaluman (10,64 %) affichent des teneurs élevées en protéines brutes. Aucune corrélation n'a été observée entre les tannins et le fer, le zinc ou les protéines brutes, ce qui indique que la sélection pour la teneur en tannins peut être réalisée sans affecter les autres caractères. Le fer, le zinc et les protéines brutes étaient positivement corrélés, impliquant qu'ils peuvent être sélectionnés conjointement pour améliorer la teneur en nutriments.

Mots Clés: Protéine, *Sorghum bicolor*, tannins, zinc

INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is a multipurpose C_4 cereal, widely adapted to low and high input environments. It survives under extreme temperature ranges, moisture deficient conditions (Dube *et al*., 2018; Sirany *et al*., 2022), and virtually all types of soil texture (Boukrouh *et al*., 2021). The adaptability is partly due to its extensive root system, dormancy-induction during drought, tolerance to salinity, high photosynthetic efficiency and ratooning ability (Boukrouh *et al*., 2021). This versatility makes sorghum an important crop in the livelihood of many people in sub-Saharan Africa (SSA) where it is produced and utilised for food, feed, beverages, fodder and biofuel (Kumar, 2016; Bhuiyan *et al*., 2024). Global production is approximately 63 million metric tonnes harvested from about 44 million hectares (Mundia *et al*., 2019), of which 62% is in the semi-arid regions of Africa (FAOSTAT, 2023). Globally, sorghum supports over 500 million people (Khoddami *et al*., 2023), ranking fifth after wheat, rice, maize and barley (FAO, 2021); and second in Africa after maize (Desta *et al*., 2022).

In Uganda, sorghum is mostly grown in semi-arid zones where it is a staple food crop (Lubadde *et al*., 2019). It is the main source of energy, protein, vitamins and minerals for over 1.5 million people in the Karamoja region of Uganda, which is perpetually affected by drought and heat leading to crop and livestock failure. The region is known as one of the world's destitute corners, where 61% of the population live in absolute poverty and over 60% of the children below 5 years and women in the reproduction age (15-49 years) are anaemic due to lack of adequate intake of zinc, iron and protein (Wamani, 2014; Muggaga *et al*., 2023). Wamani (2014) reported that 23% of the mothers between 15-49 years; and 30.7% boys and 25% girls are under-weight; while 40.3% boys and 34.6% girls are stunted; and over 50% of households suffer from food insecurity. In the region, sorghum is the only reliable source of essential nutrients such as zinc, iron and proteins which frequently lack in human diets (Paiva *et al*., 2016). Deficiency of iron and zinc results in poor growth, reduced immunity, fatigue, irritability, weakness, hair loss, sterility, morbidity and even mortality. In man, zinc and iron are required for normal body physiological and biochemical processes of the cells, cognition, reproduction, regulation of gene expression (Roohani *et al*., 2013) and immune system (Haase *et al*., 2008).

Zinc and iron are co-factors to more than 300 enzymes and about 3000 proteins are zinc dependent for transcription and transduction (Gammoh and Rink, 2019; McClung, 2019). Sorghum is also rich in tannins with antioxidants that protect sorghum against pathogens and predators (de Morais-Cardoso *et al*., 2017). However, tannins have anti-nutritional properties of inhibiting iron and zinc bioavailability; thereby contributing to deficiency of the nutrients in addition to inhibiting protein and carbohydrate absorption and digestibility which results in hidden hunger (Bae *et al*., 2016).

Information on the nutritional status of sorghum varieties grown in Karamoja zone is hardly known. This limits their inclusion in the nutritional intervention and breeding new varieties for the population. The objective of this study was to establish the nutritional status of popularly cultivated sorghum varieties in the Karamoja Sorghum-Livestock Livelihood zone of Uganda.

MATERIALS AND METHODS

Study site description. This study was conducted in three sub-counties (Iriiri, Matany and Lopei) of Napak district (2°06'56.0"N 34°13'36.0"E) in northeastern Uganda, during May to August, 2024. These sites were purposively selected based on the fact that they were the highest sorghum producers. Three parishes and one village in each parish was randomly selected for the study.

The area is generally chacterised by unimodal rainfall pattern, with a mean annual range of 400-1200 mm; and mean annual temperature range of 16-34°C. The soils of the region are predominantly sandy loams and black clays (vertisols). Akin to semiarid conditions, sorghum is among the major food security crops in this region, grown for food, beverages, and as a source of household income.

Study materials. Sorghum samples were randomly collected from 25 households in Iriiri subcounty, 20 households in Matany and 20 households from Lopei subcounties; and taken to Makerere University for nutrient analysis. The common sorghum varieties grown in the study area were landraces identified as Kabir, Ekarengit, Enyang, Liba, Lokirion and Kaluman (Longok, 2024). The landraces were selected based on preferences such as high grain yield, resistance to insect pests and diseases, tolerance to drought, taste, market preference and easy to cultivate (Longok, 2024).

Sorghum sample analysis. The sorghum samples were initially sun-dried to constant moisture content. Tannin content was determined using the modified Vanillin-HCl assay method, as described by Price *et al*. (1978). A total of 0.3 g of each variety was put into freshly prepared vanillin reagent, consisting of vanillin dissolved in an acidified alcohol solution for optimal reaction with tannins. The mixtures were incubated, and the optical density (OD) was measured at a wavelength range of 500 nm, using a spectrophotometer. The percentage of tannins was calculated based on catechin equivalents, indicating the proportion of tannins in the total sample weight. For improved representation, the percentage tannin values from duplicate measurements were averaged.

The micro-Kjeldahl method was used to estimate the percentage crude protein content (%CP) in the six sorghum landraces. Each sample of approximately 0.3 g, was taken using an analytical balance, and placed into Kjeldahl flasks for digestion process. After the Kjeldahl process, the nitrogen amount was derived from the titration data and converted to percentage crude protein, using conversion factor of 6.25.

Total iron content and zinc content (mg kg^{-1}) were determined using the Agilent 240FS Atomic Absorption Spectrophotometer, in accordance with the protocol described in AOAC (2000). By this procedure, 0.3 g from each variety was heated to 550 °C. The ashes obtained were dissolved in 1 M hydrochloric

acid (HCl), and results were obtained through spectrophotometer reading at an absorbance wavelength of 248.3 nm for iron and 213.9 nm for zinc against a blank.

Data analysis. Data collected were analysed using analysis of variance (ANOVA) in GenStat statistical software (18th Edition). Where significant differences were observed, the means were separated using Fisher's protected Least Significant Differences (LSD) at 5% level of significance. Correlation analysis was applied to tannins, iron, zinc and crude proteins. The normality and homogeneity tests were done using Shapiro-Wilk's test and Bartlet's test, respectively.

RESULTS AND DISCUSSION

Test for assumptions of homogeneity and normality. Bartlett's homogeneity test and normality test for suitability for analysis of variance (ANOVA) were done for traits assessed (Table 1). The traits passed the homogeneity and normality test basing on the P-values being greater than α=0.05. This implies that Fisher's ANOVA test could be used to assess variation.

Tannin content (%). There was significant variation in tannin content in the six sorghum landraces assessed. Variety Kabir (0.13%) had the lowest tannins content; followed by Ekarengit (0.80%), Enyang (0.99%), Liba (1.54%), Lokirion (1.78%) and Kaluman (1.97%) (Table 2). Basing on Dykes *et al*. (2014) classification of sorghum genotypes, Kabir, Ekarengit and Enyang were low-tannin varieties since they had less than 1% tannin content. The other genotypes were classified as high-tannin landraces since their tannin content was higher than 1% (10mg g^{-1}). Therefore, landraces Kabir, Ekarengit and Enyang may be used as sources of alleles for breeding for low tannin content; while Liba, Lokirion and Kaluman may be used to breed for tannin content enhancement with the intention of reducing pest and bird damage.

High tannins content has properties of undesirable texture, flavor, and taste which results in low acceptability of food products made from crops having high tannin content (Tasie *et al*., 2020). Thus, the sorghum landraces, such as Kabir, Ekarengit and Enyang, with low tannin content may be promoted for food; while the rest may be promoted for local beverage (Semere *et al*., 2023). Tannins are also known to have negative effect on the absorption of nutrients (Mahmood *et al*., 2014) from the food consumed because they can form tannin-protein or tannin-mineral complexes, especially iron and zinc (Awika, 2017), thereby reducing nutrient digestibility of the affected nutrients (de Morais Cardoso *et al*., 2017).

Crude protein (CP) content. Significant variation in percent crude protein content (8.4-12.56%) was observed in the sorghum landraces assessed; with Lokirion having the highest; followed by Enyang, Kaluman, Kabir, Ekarengit and Liba (Table 2). The significant mean differences were detected between all the landraces, except Kabir and Ekarengit. The

TABLE 1. Barlett's Homogeneity and Shapiro-Wilk normality tests

Traits	Bartlett's Chi-square value	Probability at 0.05	Shapiro-Wilk test	Probability at 0.05
Tannins (%)	2.43	0.79ns	0.92	0.32ns
CP (%)	0.06	1.00ns	0.96	0.76ns
Fe (mg kg^{-1})	6.24	0.28ns	0.97	0.92ns
Zn (mg kg^{-1})	7.61	0.18ns	0.87	0.07ns

TABLE 2. Mean content of tannins, crude proteins, iron and zinc in the sorghum landraces assessed

Genotypes	Traits			
	Tannins (%)	CP (%)	Fe (mg kg^{-1})	Zn (mg kg^{-1})
Kabir	0.13	9.63	58.70	48.21
Ekarengit	0.80	9.63	55.64	46.11
Enyang	0.99	11.76	58.29	46.63
Liba	1.54	8.40	58.45	46.19
Lokirion	1.78	12.56	61.65	52.95
Kaluman	1.97	10.64	53.87	44.19
Grand mean	1.20	10.43	57.77	47.38
P-value$_{(0.05)}$	<0.001	<.001	0.04	<0.001
Se	0.13	0.22	1.76	0.79
LSD$_{(0.05)}$	0.44	0.75	4.30	2.75
%CV	14.50	2.90	3.00	2.40

% = percent, CP = Crude proteins, Fe = Iron, Zn = Zinc

landraces may be grouped as low CP (<10% for Kabir, Ekarengit and Liba) and moderate CP (10-12% for Lokirion, Kaluman and Enyang) genotypes. However, the landraces had higher CP than the commercial cultivars, NAROSORG-2 (IS8193=8.3%) and IS8222 (5.6%), under field conditions (Tsephe *et al*., 2024; Kumar *et al.*, 2025).

The high CP content in landraces (Lokirion, Enyang and Kaluman) provide a good opportunity to enhance CP intake by man and can be used enhance CP content of the commercial sorghum cultivars in Uganda, through breeding. Landraces Kabir and Ekarengit are not fit for the breeding purpose because they have low CP; while and Liba has high tannin content, which inhibits the activity of protease and α-glucosidase enzymes. This results in inhibition of utilisation of carbohydrates and proteins by man (Bae *et al*., 2016).

Iron content (mg kg^{-1}). The landraces significantly differed (P<0.05) in iron content (Table 2). Lokirion had the highest content (61.65 mg kg^{-1}); followed by Kabir (58.70 mg kg^{-1}), Liba (58.45 mg kg^{-1}), Enyang (58.29 mg kg^{-1}), Ekarengit (55.64 mg kg^{-1}) and Kaluman (53.875 mg kg^{-1}).

Differences were noticed between Lokirion and Ekarengit, Kaluman and Kabir, Kaluman and Enyang, and Kaluman and Liba. Basing on the iron content and effect, Lokirion was the best source and thus may be used to improve cultivars that are deficient of the element. On the other hand, Kaluman is not appropriate as a source of iron because of it had a negative effect relative to the grand mean.

The significant variation of iron content in sorghum has been reported in other studies (Kotla *et al*., 2019); and attributed to the genetic differences that exist in the sorghum. Iron content was higher than the 35.3-39.4 mg kg^{-1} (Osman *et al*., 2022), and 12.50-76.64 mg kg^{-1} (Paiva *et al*., 2016) for improved cultivars. This may imply possibility for further iron content improvement. However, the iron content of the landraces assessed were 12 folds better than for cultivar IS8222 (44.80 mg kg^{-1}) (Kumar *et al*., 2025) tested and recommended for release in Uganda; and 6 folds better than the commercial cultivar NAROSORG-2 (87.01 mg kg^{-1}) (Tsephe *et al*., 2024) currently traded in Uganda. However,

the content was within the recommended dietary intake 10-50 mg day^{-1} (WHO, 2011); implying that all the sorghum landraces can adequately supply iron required on a daily basis by man.

Therefore, the landraces may be used as excellent sources of iron nutrition and crop improvement. However, the effect of tannins on iron absorption should be assessed as tannins are known to reduce iron availability before absorption, through the formation of insoluble anti-nutritional-mineral complexes (Bohn *et al*., 2008).

Zinc content (mg kg^{-1}). The landraces significantly differed (P<0.05) in zinc content (Table 2). Lokirion had the highest content (52.95 mg kg^{-1}); followed by Kabir (48.21 mg kg^{-1}), and Enyang (46.63 mg kg^{-1}). Basing on the zinc content , Lokirion was the best source of zinc; followed by Kabir and those may be used to improve cultivars that are deficient of zinc (Table 2). The variation in zinc content ranged within 8.36-51.11 mg kg^{-1} reported by Kumar *et al.* (2025) and 48.1 to 81.6 mg kg reported by Dhar *et al*. (2024) for coloured sorghum; and 14-91 mg kg^{-1} (Ashok-Kumar *et al*., 2012) for other sorghums.

The content was higher than that observed in improved cultivars such as NAROSORG2 (1.96-18.61 mg kg^{-1}) (Tsephe *et al*., 2024) and IS 8222 (33.9 mg kg^{-1}) (Kumar *et al*., 2025) currently grown in Uganda. It was also higher than in many improved varieties (Paiva *et al*., 2016; Krushiv *et al*., 2024). This implies that the tested landraces can be used to further improve the zinc content of improved cultivars.

Correlation amongst tested traits. Tannins had no significant correlation with crude proteins, iron and zinc although the relationship was positive for crude proteins and zinc but negative for iron (Table 3). Conversely, other researchers reported significant negative correlations between tannins and crude proteins (Shinda *et al*., 2022; Sejake *et al*., 2022; Tasie *et al*., 2020). The results imply that breeding for low or high tannin content may not significantly affect the performance of the other traits while the other traits may simultaneously be improved without antagonistic effect.

Crude protein had a significant positive correlation with iron and zinc (Table 3). A similar observation was reported by Kamal *et al*. (2023) and Aherkar *et al*., (2025) for iron; though Kumar *et al*. (2025) reported non-significant correlation between these parameters. The positive and significant correlation amongst crude protein, iron and zinc content indicates that simultaneous improvement for the nutrients is feasible and highly effective as also suggested by others (Venkateswarlu *et al*., 2018; Gupta *et al*., 2021; Chavan *et al*., 2023).

Iron content had a strong and positive correlation (r=0.878) with zinc content (Table 3). Similar observation was reported in other studies (Chavan *et al*., 2023; Aherkar *et al*., 2025; Kumar *et al*., 2025). This implies that breeding for iron content enhances zinc

TABLE 3. Correlation between tannins, crude proteins, iron and zinc in the sorghum landraces assessed

Traits	Tannin	Crude protein	Iron	Zinc
Tannin	-			
Crude protein	0.2991ns	-		
Iron	-0.0674ns	0.3881*	-	
Zinc	0.0137ns	0.5703**	0.8780**	-

content; and reliable modeling of one trait may be done when data for the other is provided as also shown by Kumar *et al*. (2025). Since zinc is predominantly controlled by additive gene action (Gaddameedi *et al*., 2020; Kumar *et al*., 2025), progeny selection may be appropriate to improve both elements for the landraces.

CONCLUSION

The sorghum landraces cultivated in Karamoja include Kabir, Ekarengit, Enyang, Liba, Lokirion and Kaluman. These landraces contain significantly different amounts of nutritional components, namely crude protein, iron and zinc contents; suggesting large genetic variation in the sorghum landraces. Landraces may be used as sources of alleles for the nutrients.

Kabir and Ekarengit could be used to breed for low tannins because of they had low tannin content; while breeding for low tannin content should be done for Enyang, Liba, Lokirion and Kaluman. Enyang, Lokirion and Kaluman could be used for crude protein improvement.

All landraces had high iron and zinc content so they may be used as sources of alleles to improve other genotypes for the elements. However, there is need to assess the availability of the nutrients in order to explain the high prevalence of anaemia yet the predominant food is nutrient rich.

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