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Biomass Yield, Proximate, Fibre, Minerals, and Amino Acids Compositions of Cereal-Based Hydroponic Fodder

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ABSTRACT

Background and Objective: Hydroponic fodder production is gaining attention as a sustainable method of improving forage availability and quality for livestock, hence, the objective of this study was to evaluate the yield and nutritive value of cereal-based hydroponic fodder. **Materials and Methods:** Four cereal crops (maize, wheat, sorghum, and millet) were evaluated for biomass yield, proximate composition, fiber fractions, mineral content, metabolizable energy, *in vitro* Organic Matter Digestibility (IVOMD), and amino acid profiles under a hydroponic fodder system at the University of Ibadan, Oyo, Nigeria. Statistical differences among data collected were evaluated using SPSS at a 5% level of significance. **Results:** It showed significant variations in biomass yield, with millet producing the highest fresh biomass and dry matter yields (137.25 and 109.02 ton/ha, respectively), followed by wheat, maize, and sorghum. Proximate and fibre analysis revealed that crude protein and fibre contents were highest in wheat fodder. Metabolizable energy and IVOMD results highlighted the hydroponic fodders' high digestibility and potential energy availability, with millet ranking highest. Mineral analysis indicated that calcium, phosphorus, magnesium, manganese, and zinc levels were highest in wheat. Amino acid profiling demonstrated that wheat and millet had superior essential amino acid concentrations, particularly lysine and methionine. **Conclusion:** These findings suggested that hydroponic production enhances forage quality, making it a viable alternative for improving livestock nutrition and productivity.

KEYWORDS

Hydroponic fodder, biomass yield, proximate composition, fiber, minerals, metabolizable energy, *in vitro* digestibility, amino acids

INTRODUCTION

Green fodder is an essential component of ruminant rations that enhances their performance and productivity[1]. A regular supply of green forages (fodders) to livestock is challenging, especially during the dry season when their supply declines in quantity and quality. The need to provide fresh and quality fodder for ruminant livestock all year round is essential. Hydroponic fodder is an alternative fodder source to conventional green fodder. Hydroponic fodder is the act of cultivating fodder without soil but in water or a nutrient-rich solution for 6-9 days[2]. Hydroponic fodder is produced from oats, barley, wheat,

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sorghum, maize, cowpea, and other crops[3]. The fodder, which consists of the sprout mat (root and green foliage), is completely edible and highly nutritious. Hydroponic sprouts are a rich source of nutrients and contain a grass juice factor that improves the performance of livestock[4].

The total quantity of fodder (dry or fresh weight) that can be obtained from a crop grown under hydroponic techniques as feed for livestock is essential when talking about biomass yield. This yield varies depending on several factors, including the seed type, seed quality, environmental conditions, and management practices[5]. Therefore, there is a need to explore the yield and nutrient composition of various cereal seeds for their fodder potential under hydroponic conditions.

MATERIALS AND METHODS

Study area: The study was conducted at the Teaching and Research Farm, University of Ibadan, Ibadan, Nigeria, located at Longitude 7°27'5 N and Latitude 3°53'74 E between May-August, 2023.

Plant materials: Seeds of maize (*Zea mays*), wheat (*Triticum aestium*), sorghum (*Sorghum bicolor*), millet (*Pearl millet*), and rice (*Oryza sativa*) used for the trial were freed from any chemical treatment and were sourced from a reputable agro-allied store. The seeds were subjected to viability germination before the commencement of the trial.

The seeds were cleaned from debris and other foreign materials and weighed, thereafter sterilized by soaking for 30 min in a 20% Sodium Hypochlorite solution (household bleach) to prevent mold development. Planting trays were also cleaned and disinfected. The seeds were thoroughly washed from residues of the bleach and re-soaked overnight (about 12 hrs) in borehole water before sowing.

For each seed type (species), 250 g was sown in a hydroponic tray at 1 kg/0.34 m^2 and covered with jute bags to initiate the rapid emergence of radicles.

Each planting tray containing experimental seeds was placed on shelves in the greenhouse. For seven days, it was irrigated manually twice a day (morning and evening) before the rise and set of the sun using a knapsack sprayer. The seeds were harvested on the eighth day.

At harvest, the entire mat of the fodder from each treatment (comprising the root and the green leaves) was lifted and removed from the tray and weighed with a Camry electronic scale (SKU: CA277HA2GSNAFNAFAMZ) to determine the biomass yield while a representative fresh fodder sub-samples (300 g) from each tray was taken, oven-dried at 60°C with an electric oven (Lab Dryer Forced Air Oven-DHG-9140A) until constant weight was achieved this was then used to estimate the dry matter yield. Oven-dried samples were milled using a laboratory forage grinder Retsch SM 100 to 1 mm for proximate, fibre, mineral, and amino acid compositions. Fodder efficiency is calculated as the ratio of fresh hydroponic fodder to the seeds sown.

Nutrient composition determination: Oven-dried samples were ground to pass through a 1 mm sieve and analyzed using a Near-Infrared Reflectance Spectroscopy (NIRS) device, the FOSS Forage Analyzer 2500 (NIRS™ DS2500 L), equipped with the WinISI II software with a global calibration. The analysis predicted variables including fodder nitrogen content (N), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), *in vitro* Organic Matter Digestibility (IVOMD), metabolizable energy (ME), and mineral composition. Crude protein content was calculated as nitrogen (N) multiplied by 6.25 (crude protein = N × 6.25), while IVOMD reflected the potential digestibility of the fodder[6].

Statistical analysis: All data were subjected to Two-way Analysis of Variance (ANOVA) in a Randomized Complete Block Design (RCBD) using the statistical package SPSS[7], while significant means were separated and compared using Duncan's Multiple Range Test[8] at a 5% level of significance.

RESULTS

The highest fresh biomass and dry matter yields were recorded from fodder produced from millet (137.25 and 109.02 ton/ha, respectively). This was similarly followed by wheat and maize, while the least values of 94.12 and 68.63 ton/ha were recorded from fodder produced from sorghum for fresh biomass and dry matter yields, respectively. Fodder produced from maize had the highest dry matter (DM) percentage of 30.49%, while the least DM (%) of 20.56 was recorded from the fodder produced from millet (Table 1).

The highest ($p \leq 0.05$) values for crude protein (17.90%), Ash (8.3%), crude fibre (16.43%), acid detergent fibre (28.19%), acid detergent lignin (5.49%), and neutral detergent lignin (61.77%) were recorded from fodder produced from wheat (Table 2). Value for ether extract was highest (4.07%) in the fodder produced from maize, while fodder produced from millet had the highest values of 63.42% and 9.05 (kcal/kg DM) for *in vitro* organic matter digestibility and metabolizable energy, respectively.

Highest ($p \leq 0.05$) values for Ca (4064 ppm), P (6838.92 ppm), Mg (4286.31 ppm), Mn (181.40 ppm), and Zn (47.12 ppm) from fodder produced from wheat. Proportions for Na (3483.98 ppm), K (13682 ppm), and Cu (6.79 ppm) were highest in fodder produced from sorghum (Table 3).

As recorded, the highest values ($p \leq 0.05$) for histidine, isoleusine, methionine, lysine, leucine, and tryptophan were recorded from both millet and wheat (Table 4). Values for all the non-essential amino acids evaluated were highest from the fodder produced from wheat.

Table 1: Biomass yields of cereal-based hydroponic fodder

Parameter	Maize HF	Millet HF	Sorghum HF	Wheat HF
Fresh biomass yield (ton/ha)	105.49 ± 22.27^{ab}	137.25 ± 16.01^{a}	94.12 ± 7.71^{b}	120.39 ± 18.46^{ab}
Dry matter yield (ton/ha)	73.33 ± 21.12^{b}	109.02 ± 11.78^{a}	68.63 ± 4.13^{b}	90.59 ± 23.44^{ab}
Dry matter (%)	30.49 ± 0.51^{a}	20.56 ± 1.33^{b}	27.08 ± 0.77^{a}	29.10 ± 0.81^{a}
Fodder efficiency	3.59 ± 0.73	4.09 ± 0.71	3.20 ± 0.77	4.67 ± 0.75

^{a,b,c,d}Means on the same row with different superscripts, are significantly different ($p \leq 0.05$) and ±: Standard deviation

Table 2: Proximate and fibre compositions, metabolizable energy and *in vitro* organic matter digestibility of cereal-based hydroponic fodders

Parameter (%)	Maize HF	Millet HF	Sorghum HF	Wheat HF
Dry matter	90.62 ± 2.11^{c}	90.69 ± 1.08^{b}	90.56 ± 1.47^{c}	90.77 ± 1.75^{a}
Crude protein	13.63 ± 0.08^{c}	16.61 ± 1.11^{b}	13.56 ± 1.27^{d}	17.90 ± 0.03^{a}
Ether extract	4.07 ± 0.01^{a}	2.96 ± 0.00^{c}	3.19 ± 0.04^{b}	0.88 ± 0.00^{d}
Ash	5.56 ± 1.41^{d}	7.52 ± 1.37^{b}	6.57 ± 1.25^{b}	8.30 ± 1.33^{a}
Crude fibre	14.73 ± 1.72^{c}	14.83 ± 1.24^{b}	13.45 ± 0.47^{d}	16.43 ± 1.77^{a}
Acid detergent fibre	21.36 ± 2.21^{d}	22.05 ± 2.49^{c}	22.19 ± 2.50^{b}	28.19 ± 2.22^{a}
Acid detergent lignin	4.18 ± 0.50^{d}	4.88 ± 0.21^{c}	5.01 ± 0.23^{b}	5.49 ± 0.72^{a}
Neutral detergent fibre	49.30 ± 3.75^{d}	50.33 ± 4.55^{c}	51.05 ± 3.17^{b}	56.50 ± 2.71^{a}
IVOMD	60.87 ± 2.71^{d}	63.42 ± 3.33^{a}	61.58 ± 2.37^{c}	61.77 ± 3.79^{b}
ME (kcal/kg DM)	8.74 ± 1.21^{b}	9.05 ± 2.07^{a}	8.43 ± 2.16^{c}	8.47 ± 1.67^{c}

^{a,b,c}Means within rows with unlike superscripts are significantly different from each other ($p \leq 0.05$), IVOMD: *in vitro* Organic Matter Digestibility and ME: Metabolizable energy

Table 3: Minerals content of cereal-based hydroponic fodders

Parameter (ppm)	Maize	Millet	Sorghum	Wheat
Macro				
Calcium	1773.34 ± 0.55^{c}	1873.30 ± 0.34^{b}	250.81 ± 0.22^{d}	4064.00 ± 0.07^{a}
Phosphorus	6692.28 ± 0.55^{b}	5889.53 ± 0.39^{d}	6448.58 ± 0.20^{c}	6838.92 ± 0.05^{a}
Magnesium	3952.23 ± 0.23^{d}	3979.52 ± 0.44^{c}	4060.28 ± 0.34^{b}	4286.31 ± 0.10^{a}
Sodium	2468.19 ± 0.61^{c}	2309.60 ± 0.55^{d}	3483.98 ± 0.23^{a}	2973.88 ± 0.11^{b}
Potassium	12062.05 ± 0.77^{b}	8099.10 ± 0.53^{d}	13682.28 ± 0.33^{a}	8976.86 ± 0.09^{c}
Micro				
Manganese	124.95 ± 0.44^{d}	141.20 ± 0.56^{c}	177.78 ± 0.17^{b}	181.40 ± 0.12^{a}
Ferric	252.64 ± 0.47^{c}	802.11 ± 0.51^{a}	728.78 ± 0.20^{b}	125.03 ± 0.09^{d}
Copper	5.69 ± 0.62^{d}	6.50 ± 0.53^{b}	6.79 ± 0.19^{a}	5.78 ± 0.13^{c}
Zinc	43.17 ± 0.56^{b}	41.67 ± 0.37^{c}	38.44 ± 0.17^{d}	47.12 ± 0.09^{a}

^{a,b,c,d}Means that on the same row with different superscripts are significantly different ($p \leq 0.05$) and ±: Standard deviation

Table 4: Amino acids profile of cereal-based hydroponic fodders

Parameter (ppm)	Maize	Millet	Sorghum	Wheat
Essential				
Histidine	0.18 ± 0.35^{b}	0.28 ± 0.42^{a}	0.15 ± 0.19^{b}	0.33 ± 0.03^{a}
Isoleusine	0.35 ± 0.51^{b}	0.54 ± 0.39^{a}	0.37 ± 0.20^{b}	0.54 ± 0.05^{a}
Methionine	0.15 ± 0.50^{b}	0.23 ± 0.40^{a}	0.19 ± 0.19^{ab}	0.26 ± 0.05^{a}
Lysine	0.35 ± 0.44^{b}	0.58 ± 0.41^{a}	0.31 ± 0.20^{b}	0.64 ± 0.04^{a}
Leucine	0.83 ± 0.50^{b}	1.12 ± 0.37^{a}	0.75 ± 0.22^{c}	1.10 ± 0.03^{a}
Valine	0.50 ± 0.48^{c}	0.67 ± 0.38^{b}	0.50 ± 0.21^{c}	0.76 ± 0.03^{a}
Phenylalanine	0.40 ± 0.47^{d}	0.56 ± 0.40^{b}	0.49 ± 0.17^{c}	0.65 ± 0.04^{a}
Tryptophan	0.06 ± 0.51^{b}	0.15 ± 0.40^{a}	0.09 ± 0.19^{ab}	0.14 ± 0.04^{a}
Threonine	0.23 ± 0.52^{c}	0.92 ± 0.38^{a}	0.17 ± 0.22^{c}	0.47 ± 0.05^{b}
Non-essential				
Arginine	0.32 ± 0.55^{c}	0.50 ± 0.41^{b}	0.37 ± 0.23^{c}	0.81 ± 0.04^{a}
Alanine	0.70 ± 0.50	0.80 ± 0.41	0.73 ± 0.17	0.89 ± 0.03^{a}
Tyrosine	0.30 ± 0.49^{b}	0.42 ± 0.40^{a}	0.31 ± 0.22^{b}	0.42 ± 0.05^{a}
Glycine	0.76 ± 0.51^{c}	0.80 ± 0.40^{c}	0.94 ± 0.22^{b}	1.05 ± 0.05^{a}
Aspartic acid	0.94 ± 0.44^{c}	1.11 ± 0.39^{b}	0.84 ± 0.18^{d}	1.25 ± 0.03^{a}
Serine	0.43 ± 0.50^{c}	0.51 ± 0.41^{b}	0.43 ± 0.21^{c}	0.69 ± 0.04^{a}
Proline	0.85 ± 0.50^{b}	0.55 ± 0.39^{d}	0.74 ± 0.19^{c}	0.92 ± 0.04^{a}
Glutamic acid	1.70 ± 0.45^{b}	1.51 ± 0.38^{c}	1.50 ± 0.20^{c}	1.84 ± 0.05^{a}
Cystine	0.243 ± 0.45	0.23 ± 0.36	0.21 ± 0.20	0.29 ± 0.04^{a}

[a,b,c,d]Means on the same row with different superscripts are significantly different ($p\leq0.05$) and ±: Standard deviation

DISCUSSION

Fresh hydroponic biomass yield recorded from the four cereal crops ranged between 94.12-137.25 ton/ha. These values were higher than 56.0 ton/ha, earlier reported by Bamikole *et al.*[4] from fodder grown from barley and 58-60 ton/ha from wheat and maize under a hydroponic system[2]. Hydroponic fodder produced from millet had the highest ($p\leq0.05$) fresh biomass (137 ton/ha) and dry matter (109.02 ton/ha) yields. This could be attributed to its phenological features, like long and stronger stems with longer and broader leaves that have a higher dry matter fraction. Previous research of Al-Karaki and Al-Momani[9] documented average green forage yields of 217, 200, 194, 145, and 131 ton/ha for one production cycle (8 days) for cowpea, barley, alfalfa, sorghum, and wheat, respectively. The fresh yield and dry matter content of hydroponic fodder are affected by several factors, including the type of crop, the timing of the harvest, the drainage of excess water before weighing, the type and quality of seeds, the seeding rate, any seed treatments applied, the quality of water used, pH levels, frequency of irrigation, the nutrient solution utilized, light exposure, duration of growth, temperature, humidity, and the overall cleanliness of the greenhouse[9] and genotype[3].

Higher dry matter yield in millet hydroponic fodder could be because of the efficiency of minimal uptake by its root. This current study showed that fodder produced from maize seeds has the highest dry matter percentage (DM %) when compared with others. The DM (%) is essential for evaluating the nutritional value of fodders for livestock feeding. The dry matter content of maize fodder recorded in this study was higher than 10.3-18.5% in maize fodder reported in previous studies of Fazaeli *et al.*[10]; however, lower than 34 and 35% previously reported by Bamikole *et al.*[4] from maize and wheat hydroponic fodder, respectively. This might be due to variations in climatic conditions, the variety of maize seeds planted, and the season. The DM content of 9.23-9.44% observed in this study was lower than the 12.14-19.23% DM previously reported by Assefa *et al.*[11] for various maize varieties.

The highest crude protein (CP) content ranged from 13.56% (sorghum) to 17.90% (wheat); however, CP of 13.63% recorded from maize hydroponic fodder was within 12.44 and 16.5% reported for maize[11]. The crude protein of 13.56% for hydroponic sorghum fodder was similar to the 13.94% reported for sorghum hydroponic fodder[12]. Overall, the CP content of fodder from the crop species was above 9.0%, surpassing the 7% minimum level recommended for ruminant feed[13]. If the CP content falls below 7%, animal production may decrease due to reduced voluntary intake, lower digestibility, and a negative nitrogen balance.

The ash content of 5.56 (maize hydroponic fodder)-8.30% (wheat hydroponic fodder) recorded in this study is greater than 2.3 and 4% previously reported by Kebede *et al.*[14] for hydroponic maize and barley fodders, respectively. This difference could be attributed to species type, class of plant, and stage of growth[3]. The relatively high ash contents of the fodder are probably due to its ability to chelate with other nutrients in these fodders.

The levels of NDF and ADF observed in this trial exceeded the minimum recommendations of 33 and 17%, respectively, for forage crops[15], as well as the NDF range of 25-30% and ADF range of 21-30% for dairy cows[16]. This suggested that adding hydroponic fodder as a supplement to ruminant feed will enhance performance. Forages with low NDF are typically of higher quality and are consumed at higher levels compared to those with high NDF values. The fibre values were higher than the usual values for the corresponding parameters recorded from fodder harvested conventionally within 4-8 weeks after cutback. The concentration of both macro and micro minerals in the hydroponic fodders (maize, millet, sorghum, and wheat) varied consistently. This observation agreed with the early findings of Khan *et al.*[17] where it was observed that concentrations of minerals in plants are dependent on factors such as plant species, stage of growth, and dry matter yield among many others. The highest calcium concentration was found in wheat hydroponic fodder. Phosphorus concentration ranged from 5889.53 in millet hydroponic fodder to 6839.92 ppm in wheat hydroponic fodder, which were greater than 3.68 g/kg DM recorded in a similar research of Ayan *et al.*[18]. Mineral concentration of forage is influenced by its growing medium[19] and plant factors. This variation in the mineral concentration of hydroponic fodders could be due to differences in their mineral uptake and chelating ability. Higher concentrations of calcium in the hydroponic fodder could be influenced by the stage of growth. The hydroponics fodders, except for sorghum, could supply the calcium requirement of 2600 mg/kg recommended by NRC[16] for growing small ruminants. With respect to growing small ruminants, phosphorus concentration in the hydroponic fodders is above the deficiency limit of 2.4 and 3.0 g/kg DM for heifers and dry cows, respectively[19].

Potassium concentration in the fodders was within the range of 8 g/kg recommended for beef cattle[13] for osmotic balance and metabolism in growing livestock. The fodders contained manganese and ferric concentrations that were above 40 and 50 mg/kg, respectively, suggested as an appropriate concentration for grazing and growing livestock[20]. However, the fodders had insufficient concentrations of copper and zinc to meet the minimum requirements of 8-14 mg/kg by ruminants of all classes. These cereal hydroponic fodders were found to be better than common non-leguminous fodder and could be compared to leguminous ones with respect to their crude protein and calcium contents.

The results of this study indicated a non-uniform trend in the values for the amino acid profiles of the fodder from different grains of cereal crops; this trend was like the observation by Adekeye[21] from maize and wheat fodder produced under a hydroponic system. However, fodder produced from grains of wheat was observed to have the highest volume of essential and non-essential amino acids, followed by millet, while fodders produced from both grains of maize and sorghum had the least values of the evaluated amino acids. Nonetheless, this study has been able to establish that fodder produced under a hydroponic system could be a rich source of amino acids for ruminants at different physiological states, which could meet the need for supplementation needed for sustainable productivity.

CONCLUSION

This study showed the potential of hydroponic fodder in livestock production, and that it can be produced between 8-10 days, further strengthening cereal crops as a good potential for hydroponic fodder production, which could support sustainable and profitable livestock production, especially in areas with limited land and water availability. However, further studies are needed to evaluate the anti-nutritional factors and acceptability of the fodders by the livestock.

SIGNIFICANCE STATEMENT

This study discovered that maize, sorghum, millet, and wheat can be used to produce hydroponic fodder, which can contribute significantly to the ruminants' nutrition and serve as an alternative to conventional methods of fodder production. Though there were variations in biomass yield, with millet producing the highest fresh biomass and dry matter yields (137.25 and 109.02 tons/ha, respectively), followed by wheat, maize, and sorghum, the nutrient composition of the fodder is optimal for ruminant production. It could help stakeholders in ruminant industries to produce green fodder all year round for optimum performance and production.

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