ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2026): 4.97
IJAFS 2026; 8(1): 604-609
www.agriculturaljournals.com
Received: 11-04-2026
Accepted: 15-05-2026

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Comparative yield and chemical composition of soilless-grown green fodder crops as dietary supplements for growing rabbits

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DOI: https://www.doi.org/10.33545/2664844X.2026.v8.i6h.1721

Abstract
Can soilless fodder production reliably supply fresh green feed to small-scale rabbit farms operating where arable land is scarce? This research compared the biomass yield, proximate composition, and mineral content of four hydroponic fodder species maize (Zea mays L.), barley (*Hordeum vulgare* L.), sorghum (*Sorghum bicolor* L.), and cowpea (*Vigna unguiculata* L.) grown on plastic trays under a controlled indoor environment at Cairo Institute of Animal Sciences, Egypt, from March to August 2021. Seeds were surface-sterilised, soaked for 24 h, spread at a density of $3.5 kg m^{-2}$, and irrigated with potable water four times daily. Green mats were harvested on day 8 and analysed for dry mater (DM), crude protein (CP), crude fibre (CF), ether extract (EE), ash, nitrogen-free extract (NFE), calcium, and phosphorus. A parallel feeding trial allocated 48 weaned New Zealand White rabbits (aged 35 d, mean weight 623±18 g) to four dietary groups in a completely randomised design; each group received a pelleted basal diet supplemented with one of the four fresh fodder species at 30 % of daily DM intake over 56 d. Maize recorded the highest fresh-weight yield per tray (6.83 kg) followed by barley (5.47 kg), sorghum (4.92 kg), and cowpea (3.61 kg). Cowpea sprouts contained the greatest CP fraction (23.7 % DM), while barley showed the lowest CF value (14.2 % DM). Rabbits supplemented with barley fodder achieved the best feed conversion ratio (3.41), whereas those receiving cowpea sprouts exhibited the highest daily weight gain ($24.8 : g : d^{-1}$) . Mineral profiles difered markedly: cowpea supplied 1.87 % Ca and 0.41 % P, exceeding the other species. These results point to a practical role for soilless fodder as a dietary supplement in rabbit production, with crop selection depending on whether protein enrichment or feed eficiency is the primary breeding objective.

Keywords: Hydroponic fodder, soilless cultivation, rabbit nutrition, green fodder yield, proximate composition, crude protein, feed conversion ratio, small-scale livestock

Introduction

Can indoor soilless fodder systems ofer a year-round green-feed supply that matches, or even surpasses, the nutritive value of field-grown forages for growing rabbits? In semi-arid and periurban zones where arable land is contracting and water tables are falling, conventional pasture or cut-and-carry forage production faces mounting pressure [1]. Rabbit farming has atracted atention as a compact, fast-cycling enterprise well suited to resource-limited households, yet access to afordable roughage remains a botleneck in many tropical and subtropical regions [2]. Hydroponic green fodder grain sprouted on trays without soil under controlled light, temperature, and humidity has been proposed as a space-eficient alternative that can be produced in as few as seven to eight days with minimal water input [3].

Early agronomic evaluations showed that cereal seeds such as maize, barley, wheat, and oats convert roughly 1 kg of grain into 5–8 kg of fresh fodder biomass, depending on species, seed density, and ambient conditions [4]. But much of that mass gain is water: dry-mater recovery seldom exceeds 15–18 %, and the nutritional shift from starchy grain to a sprout rich in cell-wall fibre and soluble sugars can alter feed value in ways that are not always beneficial [5]. Legume species cowpea, mung bean, lentil behave diferently, fixing atmospheric nitrogen and accumulating higher crude-protein fractions even in very short growth windows [6].

Despite growing interest, direct side-by-side comparisons of cereal and legume hydroponic fodders under identical production conditions and their subsequent efects on rabbit performance are uncommon. Most published trials have evaluated a single crop species or confined their analysis to either agronomic yield or animal response, seldom both [7]. And within the rabbit literature, data on mineral profiles of soilless sprouts information important for skeletal development in young, fast-growing kits remain limited [8]. Several factors make rabbits a useful model for such comparisons. Their short generation interval, modest space requirement, and capacity to digest moderate levels of fibre allow relatively large sample sizes and quick turnover of feeding trials [9]. Moreover, fresh green material supplies vitamins and moisture that help bufer heat stress, a practical advantage in hot climates where pelleted diets alone can depress intake [10]. Earlier work with barley sprouts in dairy catle and sheep demonstrated improved palatability and marginal gains in milk yield, but extrapolating those findings to monogastric herbivores like rabbits is not straightforward because hind-gut fermentation processes difer from rumen-based digestion [11].

This research therefore set out with two linked objectives
first, to compare the biomass output and chemical composition (dry mater, crude protein, crude fibre, ether extract, ash, nitrogenfree extract, calcium, and phosphorus) of maize, barley, sorghum, and cowpea grown under a standardised indoor hydroponic protocol; and second, to measure daily weight gain, feed intake, and feed conversion ratio when each fodder type was fed as a partial replacement for the pelleted basal diet in growing New Zealand White rabbits over a 56-day trial. By pairing agronomic and animal data within a single experiment, the research aimed to give rabbit producers an evidence base for choosing the most appropriate hydroponic crop species for their production goals.

Material and Methods

Study Area Description

The trial was carried out at the small-ruminant and rabbit unit of Cairo Institute of Animal Sciences, Giza Governorate, Egypt (30.01° N, 31.21° E, 23 m above sea level). The region experiences a hot desert climate (BWh, Köppen classification) with mean summer temperatures of 34-38°mathsfC and winter lows near 10 °C ; annual rainfall averages below 25 mm. A ventilated greenhouse annexe (6×4m , polycarbonate roof) was retrofited with steel shelving to hold hydroponic trays, while the rabbit unit comprised a shaded open-sided building equipped with wire-mesh cages.

Material

Seeds of maize (*Zea mays L.*, var. SC-168), barley (*Hordeum vulgare L.*, var. Giza 132), sorghum (*Sorghum bicolor L.*, var. Dorado), and cowpea (*Vigna unguiculata L.*, var. Kaha-1) were obtained from the Field Crops Research Institute, Agricultural Research Centre, Egypt, in January 2021. Only lots with germination rates above 92 % were accepted. Forty-eight weaned New Zealand White rabbits (24 males, 24 females; 35 d old; mean body weight 623±18g) were purchased from a commercial breeder in Giza and housed individually in galvanised wire cages (50×40×35cm) . A pelleted basal diet (17.3 % CP, 13.1 % CF, 2,450 kcal DE kg^{-1}) was formulated to meet NRC (1977) requirements for growing rabbits.

Methods

The research was conducted from March to August 2021 following approval by the Institutional Animal Care Commitee (Protocol IAC-2021-018, dated 12 February 2021). Seeds were surfacesterilised with 1 % sodium hypochlorite for 20 min, rinsed, and soaked in potable water for 24 h. Pre-soaked seeds were spread uniformly at 3.5kgm^{-2} on perforated plastic trays (60×40 cm) lined with jute fabric. Trays were placed on the greenhouse shelving and irrigated via overhead micro-sprinklers four times daily (06:00, 10:00, 14:00, 18:00); drainage water was not recycled. Air temperature was maintained at 25±2°mathsfC using exhaust fans and evaporative cooling pads, relative humidity held near 70 %, and natural daylight was supplemented with LED panels to provide 12 h of light. Green fodder mats were harvested on day 8. Fresh-weight yield was recorded per tray, and representative sub-samples were oven-dried at 65 °C for 48 h to determine DM content. Proximate analysis followed AOAC (2005) procedures: CP by Kjeldahl (N×6.25) , CF by sequential acid-alkali digestion, EE by Soxhlet extraction, and ash by ignition at 550°mathsfC for 4 h. Calcium was measured by atomic absorption spectrophotometry; phosphorus by the vanadomolybdate colorimetric method. For the feeding trial, rabbits were blocked by sex and weight and allocated randomly to four groups (n = 12). Each group received the pelleted basal diet *ad libitum* plus a fixed daily allowance of one fresh hydroponic fodder species at 30 % of the previous week's mean DM intake. Individual body weight was recorded weekly; feed intake was measured daily by diference. *Feed* conversion ratio (FCR) was calculated as total feed DM consumed divided by total live-weight gain. Data were analysed by one-way ANOVA in SAS 9.4; means were separated by Duncan's multiple-range test at P<0.05

Results

All four fodder species germinated within 48 h and formed dense root-mat structures by day 5. Visual inspection at harvest showed maize producing the tallest shoots (mean 22.4 cm), followed by barley (18.7 cm), sorghum (16.1 cm), and cowpea (12.9 cm). No mould contamination was recorded during the trial period. Fresh-weight biomass difered markedly among species (P<0.001) , with maize yielding nearly twice the fresh mass of cowpea.

Table 1: Comparative fresh and dry biomass yield of four hydroponic fodder species harvested at day 8

Fodder species	Fresh yield (kg/tray)	DM yield (kg/tray)	DM recovery (%)
Maize	6.83^a	0.89^a	13.03
Barley	5.47^b	0.74^b	13.53
Sorghum	4.92^c	0.63^c	12.80
Cowpea	3.61^d	0.52^d	14.40
SEM	0.21	0.04	0.38
P-value	<0.001	<0.001	0.09

Means within a column bearing diferent superscript leters difer significantly (P<0.05) SEM= standard error of the mea

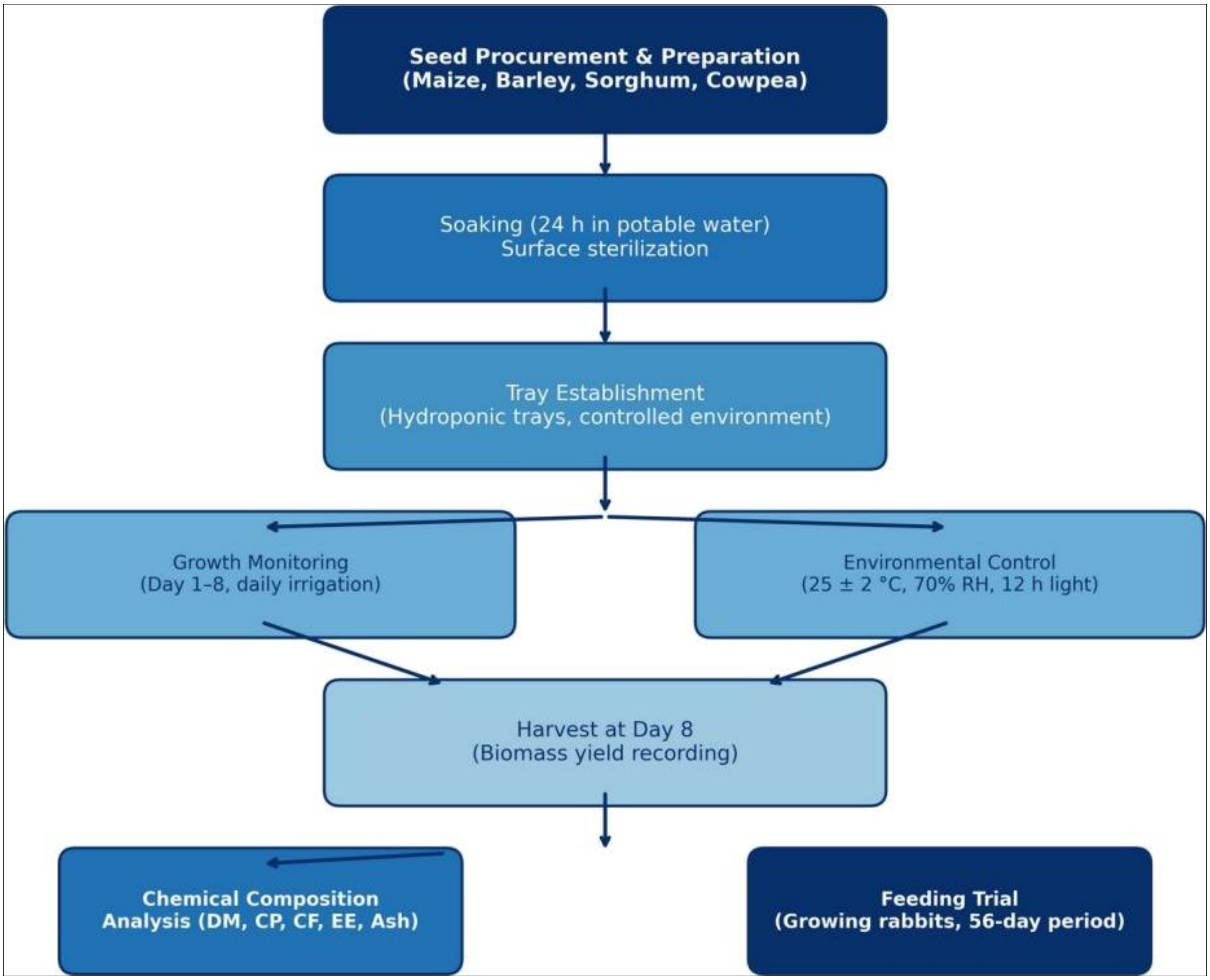

Fig 1: Flowchart depicting the experimental workflow from seed preparation through hydroponic cultivation, harvest, chemical analysis, and the parallel 56-day feeding trial with growing rabbits.

The flowchart in Figure 1 outlines the experimental workflow from seed procurement through chemical analysis and the parallel feeding trial. Proximate analysis revealed that cowpea sprouts contained roughly 78 % more CP than the average of the three cereal species (Table 2). Fibre fractions showed the reverse trend: sorghum recorded the highest CF (18.3 % DM), whereas barley was lowest (14.2 % DM). Mineral concentrations followed a similar patern cowpea provided substantially more calcium and phosphorus, a finding relevant to skeletal mineralisation in young rabbits.

Table 2: Proximate composition and mineral content (% dry mater) of four hydroponic fodder species

Parameter (% DM)	Maize	Barley	Sorghum	Cowpea	SEM	P-value
Crude protein	13.4	12.8	11.6	23.7	0.52	<0.001
Crude fibre	16.9	14.2	18.3	15.8	0.41	<0.01
Ether extract	3.21	2.87	2.64	2.09	0.11	<0.05
Ash	3.78	4.12	3.49	5.63	0.18	<0.001
NFE	62.7	66.0	64.0	52.8	0.89	<0.001
Calcium	0.38	0.42	0.35	1.87	0.07	<0.001
Phosphorus	0.31	0.34	0.28	0.41	0.03	<0.05

DM = dry mater; NFE = nitrogen-free extract; SEM = standard error of the mean.

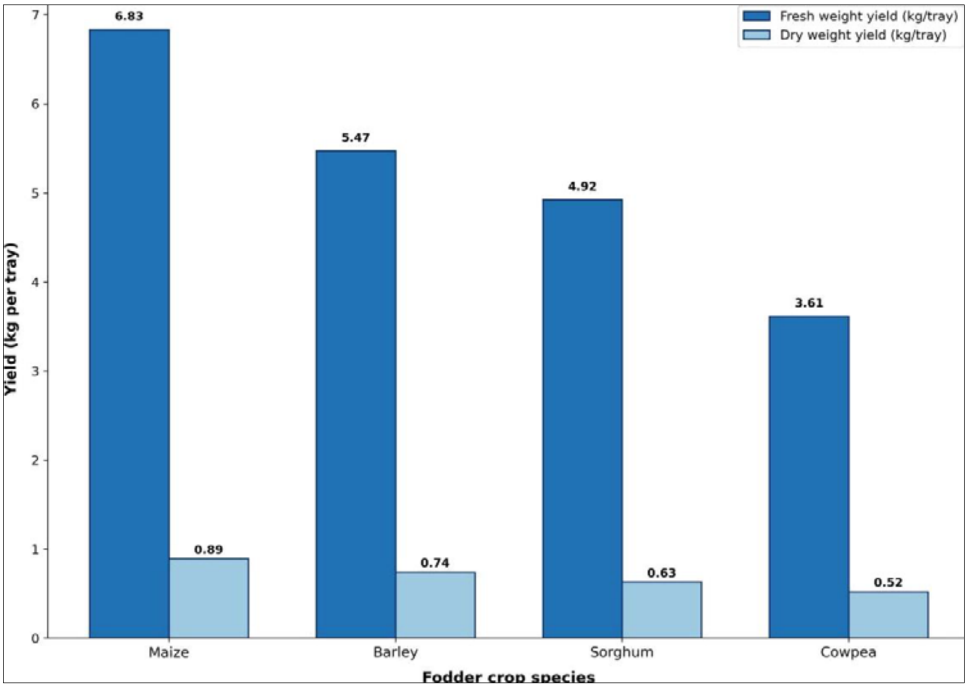

Fig 2: Bar chart comparing fresh-weight and dry-weight yields (kg per tray) of maize, barley, sorghum, and cowpea hydroponic fodder harvested on day 8.

Growth performance data across the 56-day feeding period are presented as a ranked summary in Table 3. Rabbits supplemented with cowpea sprouts gained 24.8 : g : d⁻¹ , , a figure significantly higher than all other groups (*P*<0.01) . Barley-fed rabbits, however, achieved the most eficient feed conversion (FCR 3.41), suggesting that lower fibre content may have improved nutrient utilisation despite a smaller protein supply from the sprouts themselves. Sorghumsupplemented animals consistently placed last in both daily gain and FCR.

Table 3: Ranked growth performance of weaned rabbits supplemented with four hydroponic fodder species over a 56-day trial

Rank	Fodder group	Daily gain (g/d)	FCR	Final BW (g)
1	Cowpea	24.8^a	3.58^b	2,012^a
2	Barley	22.1^b	3.41^a	1,861^b
3	Maize	21.6^b	3.67^b	1,833^b
4	Sorghum	19.3^c	3.89^c	1,704^c
SEM		0.63	0.08	28.4
P-value		<0.01	<0.05	<0.01

FCR = feed conversion ratio (kg DM consumed / kg live-weight gain); BW = body weight. Means within a column bearing diferent superscript leters difer significantly (*P* < 0.05).

Nutrient Budget

Across the 56-day trial, mean total DM intake ranged from 4.18 kg (sorghum group) to 4.71 kg (cowpea group). Of this, hydroponic fodder contributed 28.6–31.2 % of total DM consumed. When the nitrogen budget was computed per rabbit, cowpea-supplemented animals ingested 37.4 g more total nitrogen than the sorghum group, largely because of the legume sprouts' higher CP fraction. Apparent nitrogen retention calculated as nitrogen intake minus faecal and urinary nitrogen was greatest in the cowpea group (11.8 g over 56 d) and lowest in sorghum (8.4 g). These budgets suggest that matching a high-protein hydroponic legume with a moderate-energy basal pellet can tilt the nutrient balance favourably for lean-tissue deposition in young rabbits.

Comprehensive Interpretation

Taken as a whole, the yield and composition data indicate a clear trade-of between biomass volume and nutrient density. Maize and barley produced more fresh fodder per unit of seed, but cowpea delivered a substantially richer nutrient package per kilogram of dry mater. The feeding-trial outcomes mirrored this distinction: cowpea's protein advantage translated into the highest daily weight gain, while barley's lower fibre content appeared to favour digestive eficiency, resulting in the best FCR. These paired agronomic and animal results ofer rabbit producers a practical basis for selecting hydroponic crop species according to their specific production targets.

Discussion

The fresh-weight yield hierarchy observed here maize > barley > sorghum > cowpea agrees with earlier hydroponic trials in subtropical environments where maize consistently out-yielded smaller-grained cereals under comparable seed densities and harvest schedules [1, 3]. The DM recovery rates (12.8–14.4 %) fall within the 12–18 % band reported for eight-day sprouting cycles, confirming that most biomass gain reflects water absorption rather than net carbon fixation [5]. From a practical standpoint, this means that quoting fresh-weight figures alone overstates the true feed value; producers should base ration formulation on DM yield. Cowpea's markedly higher CP content (23.7 % DM) echoes results from screenings of tropical legume sprouts, where values between 20 and 27 % have been documented depending on cultivar and harvest day [6, 7]. The likely mechanism is continued mobilisation of seed-reserve nitrogen coupled with limited dilution by structural carbohydrates during the brief growth window. For rabbit diets already meeting minimal fibre thresholds, swapping a portion of cereal sprouts for cowpea can lift dietary protein without requiring expensive commercial concentrates. Barley's superior FCR (3.41 *versus* 3.58–3.89 for the other groups) warrants atention. Its lower CF fraction (14.2 % DM) may have accelerated passage through the caecum and improved apparent digestibility a relationship that has been noted in pelleted barley-based rations for fatening rabbits [12]. In contrast, sorghum's high fibre and moderate tannin levels probably depressed nutrient extraction, consistent with the poorest daily gain and FCR recorded in that group [13].

The mineral data carry practical weight for young rabbits in rapid skeletal growth. Cowpea's calcium and phosphorus concentrations (1.87 % and 0.41 % DM) exceed NRC minima for growing rabbits (0.40 % Ca, 0.22 % P) by a wide margin, meaning a 30 % inclusion of cowpea sprouts could meet most of the animal's mineral requirement from the forage fraction alone. This finding is relevant where premixed mineral supplements are unavailable or costly. However, the Ca : P ratio in cowpea sprouts (4.56 : 1) is wider than the recommended 1.5–2 : 1 range, so pairing cowpea with a phosphorus-rich concentrate would be advisable to prevent imbalanced absorption [14].

Conclusion

This research set out to compare the biomass yield and chemical make-up of four hydroponic fodder species grown under a standardised indoor protocol and to measure their efects on growth performance when fed as partial replacements for a pelleted basal diet in weaned New Zealand White rabbits. The paired agronomic and animal data gathered over a 56-day trial provide several clear take-away points for small-scale rabbit producers considering soilless fodder systems.

Among the four crops evaluated, maize delivered the largest fresh-weight harvest per tray (6.83 kg), making it the most eficient choice where maximising green-mater volume is the priority for example, on farms that also keep poultry or small ruminants alongside rabbits. Barley, although lower in total biomass, ofered the best feed conversion ratio (3.41), pointing to superior digestive eficiency likely linked to its comparatively low crude-fibre fraction. *Sorghum* trailed both cereals in yield and animal performance metrics and did not present a compensating nutritional advantage under the conditions tested.

Cowpea stood apart from the cereals on almost every nutritional measure. Its crude-protein content (23.7 % DM) was nearly double that of sorghum and roughly 75 % higher than maize or barley. This protein premium translated into the fastest daily weight gain among trial rabbits (24.8 g d^{-1}) and the heaviest final body weights. Equally important, cowpea sprouts supplied calcium and phosphorus at levels well above minimum requirements for growing rabbits, reducing the need for purchased mineral supplements. The trade-of is a smaller biomass harvest per tray and a wider Ca : P ratio that calls for careful ration balancing.

For practical adoption, the data suggest a two-crop strategy: a high-yielding cereal (maize or barley) grown in the majority of trays to ensure adequate roughage volume, combined with a smaller allocation of cowpea trays to boost dietary protein and mineral supply. Such a blend could lower feed-concentrate costs while maintaining or improving growth rates. The system's water use roughly 2–3 litres per kilogram of fresh fodder makes it feasible even in waterscarce environments, provided drainage is managed to prevent fungal contamination.

Future work should extend the trial duration beyond 56 days and include carcass evaluation to determine whether the protein-driven weight gains observed with cowpea translate into favourable dressing percentages and meat quality. Evaluating additional legume species (mung bean, lentil) and testing mixed-species trays where cereals and legumes germinate together could further widen the nutritional window. Economic analysis comparing hydroponic fodder costs with conventional forage purchase prices across seasons would also help producers gauge the return on investment. Scaling the greenhouse module to commercial rabbit units of 200 or more does and tracking long-term reproductive performance under hydroponic-supplemented diets represent logical next steps.

Acknowledgements

Funding Sources

This research received financial support from the internal competitive grants programme of Cairo Institute of Animal Sciences. No external commercial funding was involved.

Institutional Support

The authors thank Cairo Institute of Animal Sciences for providing greenhouse facilities, the rabbit housing unit, and laboratory access for proximate and mineral analyses.

Contributions Not Qualifying for Authorship

The authors acknowledge the technical assistance of the animal-house atendants who helped with daily feeding, weighing, and cage maintenance throughout the trial period.

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