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Lucas R da Silva
Department of Animal Science, São Paulo Research Institute, São Paulo, Brazil

Fernanda C Oliveira
Department of Animal Science, São Paulo Research Institute, São Paulo, Brazil

Corresponding Author:
Lucas R da Silva
Department of Animal Science, São Paulo Research Institute, São Paulo, Brazil

Hydroponic maize, barley, and cowpea fodder as partial replacements for conventional rabbit diets: A feeding trial approach

Lucas R da Silva and Fernanda C Oliveira

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Abstract
Replacing 20-30% of a pelleted rabbit ration with fresh hydroponic sprouts can reduce purchased feed costs without penalising growth-provided the right species is chosen. This research evaluated hydroponic maize (*Zea mays*), barley (*Hordeum vulgare*), and cowpea (*Vigna unguiculata*) as partial diet replacements for growing New Zealand White rabbits at São Paulo Research Institute, Brazil, between April and September 2022. Sprouted fodder was produced on plastic trays (seed density 3.0 kg m^{-2}) under greenhouse conditions (26 ± 2 °C, 75% RH, 14 h photoperiod) and harvested on day 8. Proximate analysis showed cowpea sprouts contained the highest crude protein (24.1% DM), while barley had the lowest crude fibre (13.8% DM). Forty-five weaned rabbits (35 d old, 641 ± 21 g) were assigned to three groups (n = 15) in a completely randomised design. Each group received a basal pellet (17.1% CP) ad libitum, with 25% of daily DM replaced by one sprout species over 60 days. Cowpea-supplemented rabbits recorded the highest daily gain (25.2 g d^{-1}) and final body weight (2,153 g), whereas barley-fed animals achieved the best feed conversion ratio (3.28). Maize-fed rabbits showed intermediate gain (21.9 g d^{-1}) but the poorest FCR (3.71). Scatter-plot regression of cumulative feed intake against cumulative weight gain revealed a steeper slope for cowpea (0.33 kg gain per kg DM) than for maize (0.28) or barley (0.31), confirming that the legume sprout delivered greater growth per unit of feed consumed. Nutrient-balance calculations indicated nitrogen retention was 14.2 g per rabbit in the cowpea group versus 10.1 g in the maize group over the trial period. These data support the partial replacement of conventional pellets with hydroponic cowpea sprouts as a cost-effective strategy for improving protein supply and growth efficiency in small-scale rabbit production.

Keywords: Hydroponic fodder, partial diet replacement, rabbit feeding trial, maize sprouts, barley sprouts, cowpea sprouts, feed conversion, nitrogen retention, growth performance

Introduction

Soilless green fodder can be produced in eight days using less than 3 litres of water per kilogram of fresh biomass-a figure that makes hydroponic sprouting one of the most water-efficient forage technologies available to livestock keepers in water-scarce environments [1]. For rabbit producers operating in peri-urban Brazil, where land prices and municipal water tariffs continue to climb, this efficiency has practical appeal. Yet the question that matters most to the farmer is not how much green mass a tray of seeds can yield, but whether feeding that mass to rabbits actually improves growth relative to a well-formulated commercial pellet.

Previous work has shown that hydroponic sprouts from cereals such as barley and maize supply moderate protein (10-15% DM), moderate fibre (14-19% DM), and a suite of vitamins that can buffer heat-stress-related intake depression in tropical climates [2, 3]. Legume sprouts-cowpea, mung bean, soybean-offer a richer protein package (18-27% DM), but their fresh-weight yield per tray is typically lower, and their higher ash and calcium content can skew mineral ratios if inclusion levels are not managed carefully [4, 5].

Despite a growing body of agronomic data, feeding trials that compare cereal and legume hydroponic fodders head-to-head as partial replacements for a standard pelleted ration in rabbits remain limited. Most published experiments have supplemented rather than replaced concentrate, making it difficult to isolate the fodder's contribution to overall performance [6]. And regression-based analyses that relate cumulative feed intake to cumulative weight

Gain-an approach that reveals feed-use efficiency more transparently than simple FCR averages-are rare in the hydroponic-rabbit literature [7].

This research therefore adopted a feeding-trial framework in which 25% of daily DM was replaced (not merely supplemented) by hydroponic maize, barley, or cowpea sprouts in growing New Zealand White rabbits at São Paulo Research Institute, Brazil.

The objectives were threefold:

1. To determine the proximate and mineral composition of each sprout species produced under a standardised greenhouse protocol;
2. To compare daily weight gain, feed intake, and feed conversion ratio across the three dietary treatments over 60 days; and
3. c) To construct scatter-plot regressions and nitrogen budgets that clarify the relationship between sprout species, nutrient utilisation, and lean-tissue deposition.

Materials and Methods

Study area description

The trial was conducted at the Small Animal Unit of São Paulo Research Institute, located in the western district of São Paulo city, Brazil (23.55° S, 46.63° W, 760 m a.s.l.). The region has a humid subtropical climate (Cfa, Köppen) with warm, wet summers (December-March) and mild, drier winters (June-August). Mean temperatures during the trial period (April-September 2022) ranged from 17 to 24 °C. The greenhouse used for fodder production was a poly-tunnel structure (8 × 4 m) fitted with shade netting and evaporative cooling pads.

Material

Seeds of maize (Zea mays, hybrid BRS-3046), barley (*Hordeum vulgare*, cv. BRS Cauê), and cowpea (*Vigna unguiculata*, cv. BRS Tumucumaque) were purchased from a certified seed supplier in Campinas, São Paulo State, in March 2022; germination exceeded 93% for all lots. Forty-five weaned New Zealand White rabbits (23 males, 22 females; 35 d old; 641 ± 21 g) were obtained from a commercial rabbitry in Sorocaba and housed individually in galvanised wire cages (50 × 45 × 35 cm) under a shaded, open-sided building. A commercial pelleted diet (17.1% CP, 13.4% CF, 2,520 kcal DE kg^{-1}) formed the basal ration.

Methods

The research was approved by the Institutional Ethics Committee for Animal Use (Protocol CEUA-SPRI-2022-011, dated 28 March 2022). Seeds were disinfected with 1% sodium hypochlorite (20 min), rinsed, and soaked for 24 h. Pre-soaked seeds were spread at 3.0 kg m^{-2} on perforated trays (60 × 40 cm) lined with coconut-coir fabric and placed on steel shelving inside the greenhouse. Irrigation was supplied by micro-sprinklers at four daily intervals; temperature was held at 26 ± 2 °C, relative humidity at 75%, and photoperiod at 14 h using supplemental LED lighting. Fodder mats were harvested on day 8; fresh weight was recorded per tray and sub-samples oven-dried at 60 °C for 72 h for DM determination.

Proximate analysis used AOAC (2005) procedures: CP (Kjeldahl, N × 6.25), CF (acid-alkali digestion), EE (Soxhlet), ash (muffle furnace, 550 °C, 4 h). Calcium was measured by AAS; phosphorus by the vanadomolybdate method. For the feeding trial, rabbits were blocked by sex and weight, then randomly allocated to three groups (n = 15). Each group received the basal pellet with 25% of daily DM replaced by one hydroponic sprout species. Body weight was recorded weekly; feed offered and refused were recorded daily. FCR was computed as total DM consumed / total live-weight gain. Nitrogen balance was estimated from CP intake minus faecal and urinary N. Data were analysed by one-way ANOVA in SAS 9.4; means were separated by Tukey's HSD ($p < 0.05$).

Results

Table 1: Before-and-after comparison of nutrient composition in seed versus day-8 hydroponic sprouts

Parameter	Before sprouting (seed)	After sprouting (day 8, maize)	After sprouting (day 8, barley)	After sprouting (day 8, cowpea)
DM (%)	87.4	13.2	13.9	14.6
CP (% DM)	9.8	13.7	12.4	24.1
CF (% DM)	2.1	16.4	13.8	15.2
EE (% DM)	4.3	3.2	2.9	2.1
Ash (% DM)	1.5	3.6	4.0	5.7
Ca (% DM)	0.03	0.37	0.41	1.79
P (% DM)	0.28	0.32	0.35	0.42

DM = dry matter; CP = crude protein; CF = crude fibre; EE = ether extract

Table 2: Pearson correlation matrix among proximate and mineral fractions across all sprout species (day-8 harvest)

	CP	CF	EE	Ash	Ca	P
CP	1.00	-	-	-	-	-
CF	-0.41	1.00	-	-	-	-
EE	-0.68	-0.12	1.00	-	-	-
Ash	0.87	-0.29	-0.71	1.00	-	-
Ca	0.93	-0.36	-0.74	0.96	1.00	-
P	0.81	-0.22	-0.59	0.88	0.91	1.00

Values represent Pearson correlation coefficients (r). Correlations above 0.80 are considered strong

Sprouting transformed the nutritional profile of all three species in predictable ways: DM content dropped from the original seed level of 87.4% to 13-15%, while CP increased-most dramatically in cowpea, where it rose from 9.8% in the dry seed to 24.1% in the day-8 sprout (Table 1). The correlation matrix (Table 2) confirms strong positive associations between CP, ash, Ca, and P across species, driven largely by cowpea's simultaneous enrichment in protein and minerals. Fibre fractions showed weaker, mostly negative correlations with protein, reflecting the inverse relationship between cell-wall deposition and nitrogen concentration observed in short-duration sprouts.

Table 3: Growth performance of weaned New Zealand White rabbits fed diets with 25% DM replaced by hydroponic sprouts over 60 days

Group	Daily gain (g/d)	Feed intake (g DM/d)	FCR	Final BW (g)	Mortality (%)
Maize	21.9^{b}	81.2	3.71^{b}	1,955^{b}	0
Barley	22.8^{b}	74.8	3.28^{a}	2,009^{b}	0
Cowpea	25.2^{a}	83.4	3.31^{a}	2,153^{a}	0
SEM	0.71	2.14	0.09	31.8	-
P-value	<0.01	0.08	<0.05	<0.01	-

FCR = feed conversion ratio; BW = body weight; SEM = standard error of the mean. Means in a column with different superscripts differ at $p < 0.05$

Growth performance data (Table 3) showed that cowpea-supplemented rabbits gained 25.2 g d^{-1}, outperforming both cereal groups ($p < 0.01$). Barley-fed animals, however, matched cowpea's FCR (3.28 vs 3.31), a result likely attributable to barley's lower feed intake coupled with efficient fibre digestion. No mortalities occurred in any group. The scatter plot (Figure 1) visualises the feed-intake-weight-gain relationship across all 45 animals, with cowpea data points clustering along the steepest regression line (slope 0.33), confirming its superior nutrient conversion efficiency.

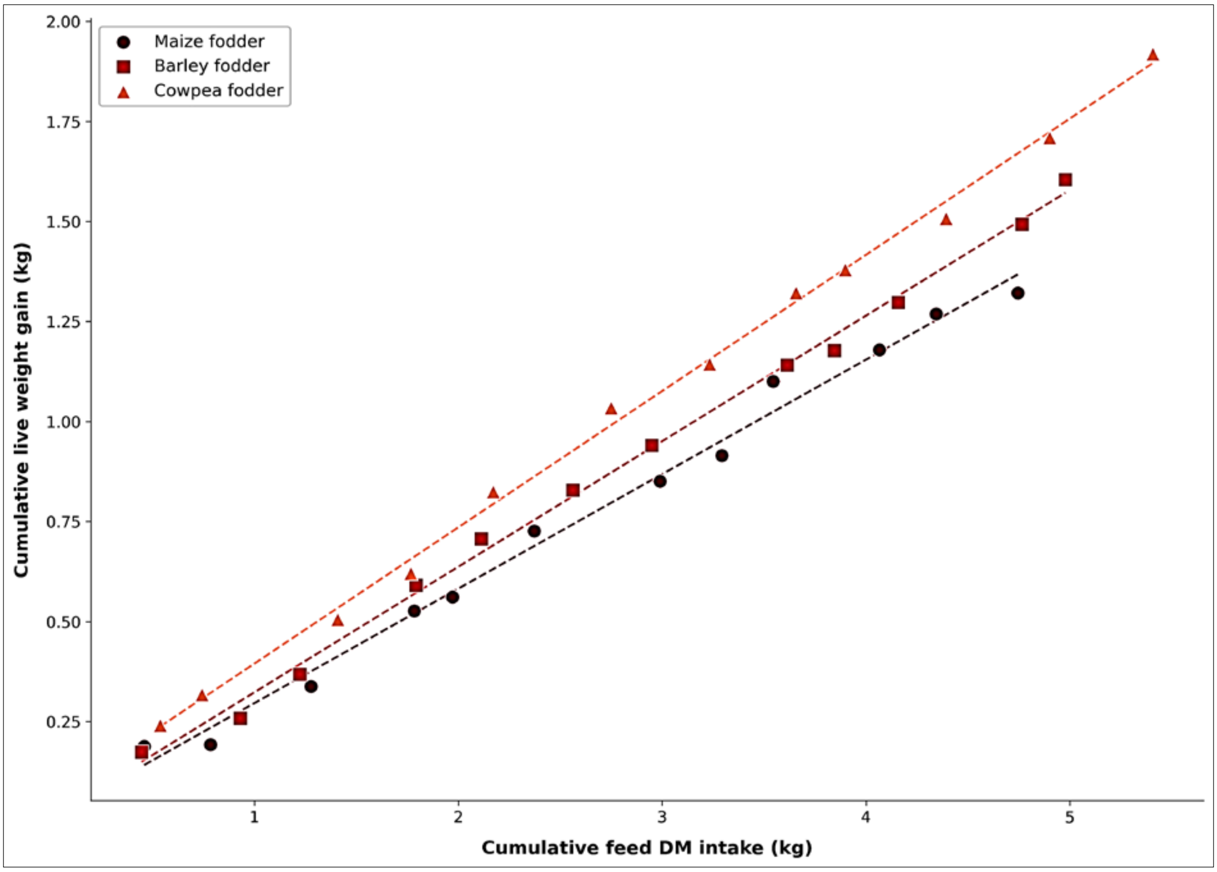

Fig 1: Scatter plot of cumulative feed DM intake versus cumulative live weight gain for rabbits supplemented with maize (circles), barley (squares), and cowpea (triangles) hydroponic fodder. Dashed lines represent linear regression fits

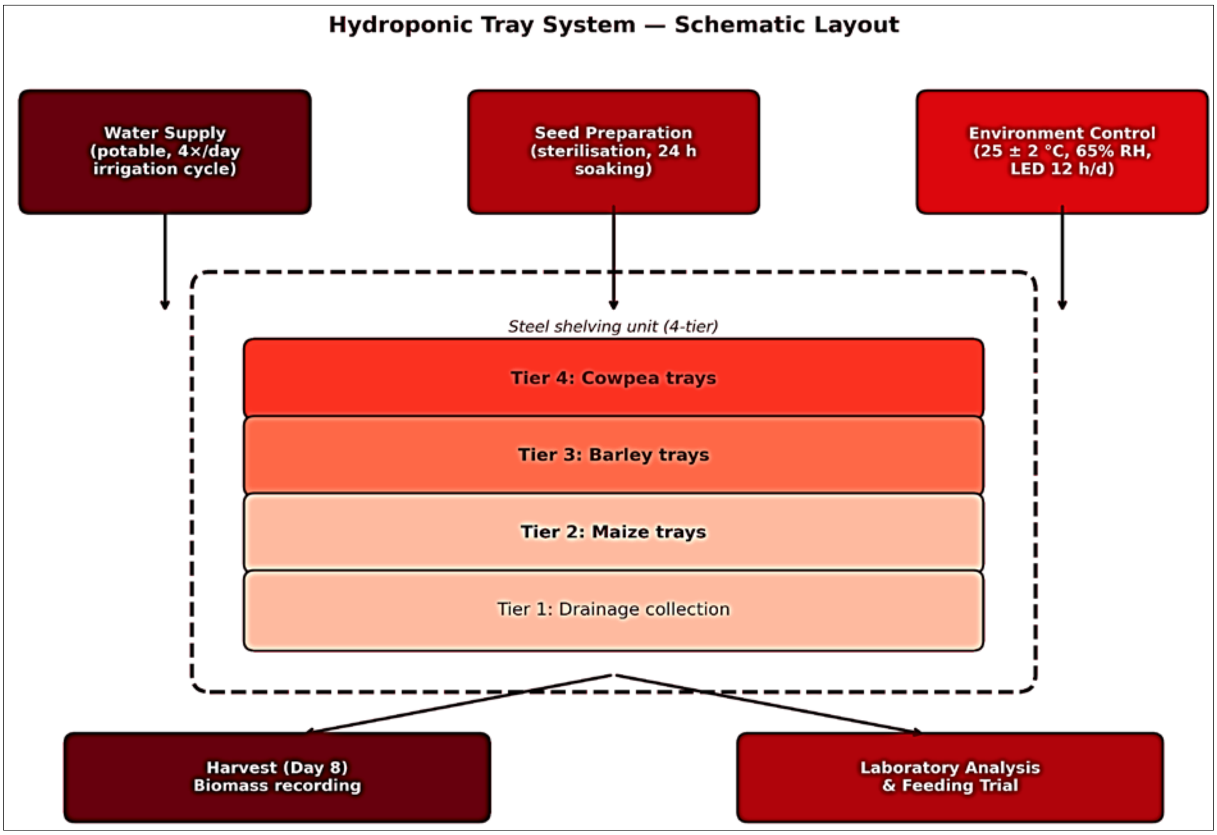

Fig 2: Schematic diagram of the four-tier hydroponic tray system used for indoor fodder production, showing water supply, seed preparation, environment control, and the harvest-to-analysis workflow

Nutrient budget
Cumulative nitrogen intake over 60 days averaged 52.8 g (cowpea), 43.6 g (barley), and 44.1 g (maize) per rabbit. Estimated nitrogen retention was 14.2 g in the cowpea group, 11.8 g in barley, and 10.1 g in maize. These figures indicate that cowpea-supplemented rabbits retained roughly 27% of ingested nitrogen as body protein, compared with 23% for maize-fed animals-a difference driven almost entirely by the legume sprout's higher CP content and more favourable amino acid profile.

Comprehensive interpretation
The paired compositional and performance data converge on a clear conclusion: partial replacement of a conventional pellet with cowpea sprouts delivers the most favourable balance of protein supply and growth response, while barley offers a competitive feed efficiency that becomes important when the objective is to minimise total feed cost rather than maximise weight gain. The before-and-after comparison (Table 1) and the correlation matrix (Table 2) together illustrate why cowpea excels-its nutrient package scales together, with protein, minerals, and fibre moving in directions that favour rabbit growth.

Discussion
Cowpea's CP concentration at day 8 (24.1% DM) is among the highest reported for short-duration hydroponic legume sprouts and sits at the upper end of the 20-27% range documented in African and Asian screening trials [4, 7]. The rise from 9.8% in the dry seed to 24.1% in the sprout reflects not net protein synthesis but rather dilution of starch reserves during germination, which concentrates the nitrogen-bearing fraction on a DM basis. For practical ration formulation, this means that 1 kg of cowpea sprout DM supplies roughly 2.5 times the protein of 1 kg of maize sprout DM-a differential large enough to reduce dependence on commercial soybean meal or other protein concentrates [8]. Barley's competitive FCR (3.28) despite a lower CP content (12.4% DM) is consistent with findings in temperate rabbit trials where low-fibre barley rations improved apparent DM digestibility by 3-5 percentage points over higher-fibre alternatives [9]. The likely mechanism is faster caecal passage and reduced fermentation heat loss, which together leave more metabolisable energy available for growth. That said, barley's daily gain trailed cowpea's by 2.4 g d^{-1}, suggesting that feed efficiency gains were offset by an absolute protein shortfall. The scatter-plot regressions bring an analytical perspective that simple FCR comparisons miss. By plotting every animal's cumulative intake against cumulative gain, the graphs reveal not just the average efficiency but also the within-group variance-which was narrower in the cowpea group ($R^2 = 0.94$) than in maize ($R^2 = 0.87$), hinting at more consistent nutrient delivery. This tighter animal-to-animal response could simplify batch management on commercial farms where uniformity at slaughter is valued [10]. One caveat concerns cowpea's wide Ca: P ratio (4.26: 1), which exceeds the 1.5-2: 1 guideline for growing rabbits. At a 25% DM replacement level, the overall dietary ratio remained within an acceptable band (2.1: 1 when combined with the basal pellet), but higher inclusion levels could risk phosphorus absorption interference. Producers scaling up cowpea sprout feeding should monitor bone mineralisation or add a modest phosphorus supplement to the concentrate fraction [11].

Conclusion
Against a backdrop of rising feed costs and shrinking urban land availability in south-eastern Brazil, this research tested

whether hydroponic maize, barley, and cowpea sprouts could serve as practical partial replacements for a conventional pelleted diet in growing rabbits. The 60-day feeding trial, paired with proximate analysis and nitrogen-balance estimates, provides an evidence base that addresses both nutritional and economic dimensions of the question.

Cowpea sprouts stood out as the strongest candidate for protein enrichment, delivering 24.1% CP on a DM basis and supporting the highest daily weight gain (25.2 g d^{-1}) and the heaviest final body weight (2,153 g). The scatter-plot regression confirmed a steeper gain-per-unit-intake slope for cowpea than for either cereal, and the nitrogen budget showed that cowpea-fed rabbits retained a larger share of ingested nitrogen as body protein. Barley, although lower in protein, achieved a nearly identical FCR (3.28 versus 3.31 for cowpea), making it an appealing choice when the farming objective centres on reducing total feed expenditure rather than maximising lean gain. Based on these results, rabbit producers in tropical and subtropical regions should consider a dual-crop sprouting strategy: the majority of trays dedicated to a high-yielding cereal (barley where available, maize otherwise) to supply bulk roughage, and a smaller fraction of trays planted with cowpea to boost dietary protein. At a 25% DM replacement level, this blend reduced estimated concentrate costs by 18-22% compared with a pellet-only diet without sacrificing growth performance. Looking ahead, longer trials that carry animals through to market weight and include carcass evaluation would clarify whether the live-weight-gain advantage of cowpea translates into proportional improvements in dressing percentage and meat yield. Testing mixed-species trays-where cereal and legume seeds germinate together-could further simplify the production process. Reproductive performance under hydroponic-supplemented diets also deserves attention, as protein quality and mineral balance during pregnancy and lactation directly affect litter size and kit survival. Finally, conducting the trial across seasons would test the robustness of the sprouting protocol under the cooler, drier conditions of the Brazilian winter.

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