Ciência Animal Brasileira
Brazilian Animal Science

DOI: 10.1590/1809-6891v25e-78582E

e-ISSN 1809-6891
Animal science | Research article

Productive and nutritional attributes of hydroponic corn forage at different stages grown in elephant grass and wood sawdust substrates

Atributos produtivos e nutricionais da forragem hidropônica de milho, em diferentes estágios, cultivada em substratos de capim-elefante e serragem de madeira

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Abstract: The objective of this study was to evaluate the productive and nutritional attributes of hydroponic corn forage grown on elephant grass and wood sawdust substrates at different stages. Two treatments (T) with different substrates were established: T1 – chopped and dehydrated elephant grass and T2 – wood sawdust. Forage samples were collected 13 and 20 days after sowing to evaluate seedling development, biomass production, and nutritional composition. The elephant grass substrate promoted better seedling development and greater biomass production and concentration of mineral matter at 13 days, whereas wood sawdust promoted a greater concentration of dry matter, crude protein, lignin, and non-fibrous carbohydrates ($P < 0.05$). The elephant grass substrates resulted in greater seedling height, production of green biomass, and concentrations of mineral matter, crude protein, and ether extract at 20 days, while wood sawdust promoted greater root length and greater concentrations of dry matter, acid detergent fiber, and lignin ($P < 0.05$). Elephant grass substrate and collection for 13 days promoted better production of hydroponic forage and its nutritional composition.

Keywords: biometry; *Pennisetum purpureum; Zea mays*

Resumo: O objetivo foi avaliar atributos produtivos e nutricionais da forragem hidropônica de milho, em diferentes estágios, cultivada em substratos de capim-elefante e serragem de madeira. Foram estabelecidos dois tratamentos (T), com diferentes substratos: T1 – capim-elefante picado e desidratado e T2 – serragem de madeira. No 13º e 20º dias após a semeadura, amostras da forragem foram coletadas para avaliação do desenvolvimento das plântulas, produção de biomassa e composição nutricional. O substrato capim-elefante promoveu melhor desenvolvimento das plântulas, maior produção de biomassa e concentração de matéria mineral, aos 13 dias, quando

Received: February 21, 2024. Accepted: May 14, 2024. Published: July 19, 2024.

a serragem de madeira promoveu maior concentração de matéria seca, proteína bruta, lignina e carboidrato não fibrosos (P<0,05). O substrato capim-elefante resultou em maior altura de plântula, produção de biomassa verde, concentração de matéria mineral, proteína bruta e extrato etéreo, aos 20 dias, quando a serragem de madeira promoveu maior comprimento de raíz, maior concentração de matéria seca, fibra em detergente ácido e lignina (P<0,05). O substrato capim-elefante e a coleta aos 13 dias promoveram melhor resultado para a produção de forragem hidropônica, bem como para a sua composição nutricional.

Palavras-chave: biometria; *Pennisetum purpureum; Zea mays*

1. Introduction

Hydroponic foraging is a technology aimed at producing plant biomass that consists of growing plants with natural or artificial substrates or even without substrates and soil. Cultivation can occur in trays inside greenhouses [(1)] or in soil covered with canvas [(2, 3)]. Studies have applied this technique to the production of forage from corn [(4, 5)], soybeans [(4)], millet [(6)], oats, barley, wheat, and sorghum [(7)]. The forage can be included in animal feed, especially during periods of food scarcity, given its nutritional quality, especially when considered in its entirety (aerial part, roots, non-germinated seeds, and the remaining substrate).

Hydroponic corn forage has a short growth cycle that accelerates its growth. The average forage cultivation time observed in these studies was 15 days from planting to harvest. Early harvests can result in low yield per unit area, whereas late harvests can cause competition between plants and reduced nutritional quality. The FAO (2001) [(7)] recommends that the harvest be carried out between 10 and 12 days, as the process of loss of nutritional quality begins from this period onwards, as observed and reported by Almeida et al. (2021) [(8)].

The use of substrates in the production of hydroponic forage contributes to increasing the dry mass content, can affect the nutritional value of the forage [(9)], and enables fixation of the root system of the seedlings, which is important for forage development [(10)]. Studies have demonstrated good results with the use of unused pastures to grow hydroponic forage [(5)]. However, no studies have reported the use of wood sawdust as a substrate for this purpose.

Wood sawdust presents desirable qualities as a substrate depending on the type of wood and its storage [(11)]. It is common to find active sawmills whose wood sawdust, considered as waste, often has no immediate use, is donated in some situations, or is sold at an affordable price in almost all cities, even small ones.

Therefore, the objective of the present study was to evaluate the productive and nutritional attributes of hydroponic corn forage grown on elephant grass and wood sawdust substrates at different stages.

2. Material and methods

The present study was carried out in the Vegetal Sector of the Experimental Farm of the Center for Agricultural, Environmental and Biological Sciences at the Universidade Federal do

Recôncavo da Bahia, located at 12°40′0″S, 39°06′0″W, and 200 meters altitude. The climate is classified by Köppen as hot and humid tropical, type Aw to Am.

The experiment was set up in a greenhouse to control water, with two treatments (T) consisting of different substrates for the cultivation of hydroponic corn forage (*Zea mays*, L.; Al-Bandeirante variety; 93% germination rate): T1 (n = 5), chopped and dehydrated elephant grass; T2 (n = 5), wood sawdust. The experimental unit (UE) was represented by a flower bed (0.45 m^2), and a completely randomized design was used to distribute the treatments in the experimental units.

Elephant grass (*Pennisetum purpureum*) was crushed in a forage machine (average size of 2.0 cm), followed by dehydration for 4 consecutive days, with turning every 2 hours. Wood sawdust, predominantly 2.5 mm particles, was purchased from local stores. Both substrates were subjected to nutritional composition analysis in triplicate (Table 1).

Table 1 **Bromatological characterization, based on dry matter, of the substrates.**

Variables (%)	Elephant grass substrate	Wood sawdust substrate
Dry matter	93.80	94.37
Mineral Matter	7.67	2.16
Organic matter	92.33	97.84
Crude Protein	2.55	1.35
Ether extract	8.96	9.70
Neutral detergent fiber	71.66	82.41
Acid detergent fiber	37.92	58.21
Cellulose	32.25	35.72
Lignin	4.25	21.14

Corn seeds were disinfected in a 2% sodium hypochlorite solution for 10 minutes, washed in running water, and subjected to osmotic conditioning, which consisted of immersing the seeds in water for 24 hours, with subsequent drainage to induce pre-germination.

The beds (0.45m^2) were set up on a leveled ground area with double-sided polyethylene canvas. The substrates were arranged in experimental units in layers 0.03 m high and moistened with water (1 L m^{-2}). Then, the corn was sown manually at a homogeneous density of 2.2 kg m^{-2}, and a new layer of substrate (0.02 m) was placed, completely covering the seeds, followed by moistening (0.5 L m^{-2}).

Watering, 2.0 L m^{-2}/day divided equally into two applications, was conducted using a conventional watering can from days 2–19 after sowing. On rainy days, the watering of the beds was suspended as the substrates maintained moisture from the previous day's watering.

Samples were collected from all beds 13 and 20 days after sowing to evaluate biometrics (seedling height and root length), production of green and dry biomass (kg m^{-2}) and nutritional composition of the forage (dry matter (DM), mineral matter (MM), crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose, lignin, estimated total digestible nutrients (TDN) and non-fibrous carbohydrate (NFC)).

Ten seedlings from each bed were collected at random and subjected to root and shoot measurements using calipers to evaluate biometrics. A sample (0.09 m^2) was then taken from each bed, and the excess substrate was removed from the samples using friction, followed by weighing to determine the production of green biomass (PGV). The production of dry biomass (PDB) was determined based on the PGV and DM content of each bed as follows: $DBS/m^2 = (PGV \times DM) / 100$.

The sample comprising the aerial part of the forage, roots, non-germinated seeds, and the remaining substrate was used to evaluate the nutritional composition. The samples were subjected to pre-drying in a forced ventilation oven, at 55 °C, for 72 hours, when they were weighed again, ground in a Willey-type mill with a 1 mm sieve, stored for analysis of DM, MM, CP, EE, NDF, ADF, cellulose and lignin, according to the protocols described in Silva and Queiroz (2002) [12]. The TDN was estimated using the equation: $TDN = 83.79 - (0.4171 \times NDF)$ [13]. NFC was calculated using the equation $NFC = 100 - MM - EE - CP - NDF$, with all terms expressed as a percentage of dry matter [14].

The data obtained were evaluated for normality using the Shapiro–Wilk test. The variables presented a normal distribution, and the data were subjected to an analysis of variance. A significance level of 5% was adopted for all the assessments.

3. Results and discussion

The elephant grass substrate promoted better seedling development and greater biomass production at 13 and 20 days; wood sawdust resulted in greater root length at 20 days ($P < 0.05$). When evaluating the influence of collection age, higher PGV and PDB were obtained at 13 days and greater seedling height at 20 days for forage grown in the elephant grass substrate and greater seedling height and root length for forage grown in wood sawdust ($P < 0.05$). Other variables were not influenced by age at collection ($P > 0.05$) (Table 2).

Table 2 Seedling biometrics and green (PGV) and dry (PDB) biomass production of hydroponic corn forage grown in different substrates and harvested at different ages.

Collection age	Variables	Elephant grass substrate	Wood sawdust substrate	P value
13 days	Seedling height (cm)	21.85 ± 4.62^{aB}	17.13 ± 3.94^{bB}	< 0.01
	Root length (cm)	17.09 ± 4.63^{a}	8.35 ± 2.82^{bB}	< 0.01
	PGV (kg m^{-2})	8.25 ± 0.91^{aA}	2.65 ± 2.25^{b}	0.004
	PDB (kg m^{-2} DM)	2.17 ± 0.24^{aA}	0.88 ± 0.75^{b}	0.017

20 days	Seedling height (cm)	28.06 ± 5.00aA	22.68 ± 5.68bA	0.010
	Root length (cm)	15.02 ± 4.24b	18.54 ± 5.32aA	0.001
	PGV (kg m^{-2})	4.40 ± 0.92aB	2.93 ± 0.49b	0.050
	PDB (kg m^{-2} DM)	1.20 ± 0.25B	0.91 ± 0.15	0.133
	P value	< 0.01	< 0.01	

The variables presented a normal distribution and the data are represented by the mean ± standard deviation. Lowercase letters in the line indicate differences between substrates. Capital letters in the column indicate differences between collection ages. ANOVA was adopted at a 5% significance level.

The results obtained for seedling development and biomass production can be justified by the chemical-bromatological composition of the substrate, since dehydrated elephant grass has a higher content of mineral matter and crude protein. Possibly the nutrients present were made available to the seedlings, which guaranteed greater development and consequently greater production of green and dry mass.

The seedlings reached values that corroborate the FAO study (2001) (7), which states that the height of hydroponic forage, depending on the growth period, can reach 20 to 30 cm. Ndaru et al. (2020) (15) obtained 27.33cm at 12 days and 37.33cm at 20 days. The same authors also reported biomass production of 1.053kg and 1.233kg at 12 and 20 days, respectively. Santos et al. (2023) (5) obtained, 13 days after sowing, a height of 13.35cm and production of 0.323kg.m^{-2} of dry mass, when using wood sawdust as a substrate.

Although the height of the seedlings increased with age, this growth was not enough to guarantee greater PGV and PDB, especially with the elephant grass substrate, which was reduced by half compared to the first harvest. This occurrence corroborates the study by FAO (2001) (7), in which it suggests that harvesting carried out between 7 and 10 days guarantees good productivity rates, unlike harvesting forage at an older age, which can result in a reduction in dry biomass and of nutritional quality. Müller et al. (2006) (6) reported a reduction from 2.28kg m^{-2} to 1.62kg m^{-2} in the dry mass production of hydroponic millet forage harvested at 10 and 20 days, respectively.

Wood sawdust promoted, at 13 days, a higher concentration of DM and CP, while the elephant grass substrate resulted in a higher concentration of MM (P<0.05) and the EE was similar between treatments (P>0.05). Wood sawdust promoted, at 20 days, a higher concentration of DM and with elephant grass, a higher concentration of MM, CP and EE was obtained (P<0.05). The collection age influenced the chemical composition of the forage. A higher concentration of MM and CP was obtained at 20 days in both substrates; and for forage grown in wood sawdust, a higher EE content was obtained at 13 days (P<0.05). The other variables were not influenced by collection age (P>0.05) (Table 3).

Table 3 Bromatological composition of hydroponic corn forage grown in different substrates and harvested at different ages.

Collection age	Variables	Elephant grass substrate	Wood sawdust substrate	P value
13 days	Dry matter	26.96 ± 2.50 ^{b}	31.70 ± 2.73 ^{a}	< 0.01
	Mineral matter	3.99 ± 0.63 ^{aB}	1.10 ± 0.52 ^{bB}	< 0.01
	Crude protein	10.21 ± 0.54 ^{bB}	10.85 ± 0.27 ^{aB}	0.010
	Ether extract	18.13 ± 2.46	18.49 ± 0.21 ^{A}	0.685
20 days	Dry matter	27.29 ± 1.10 ^{b}	30.93 ± 1.15 ^{a}	< 0.01
	Mineral matter	6.50 ± 0.92 ^{aA}	3.45 ± 0.34 ^{bA}	< 0.01
	Crude protein	12.72 ± 0.41 ^{aA}	11.83 ± 0.32 ^{bA}	0.001
	Ether extract	18.66 ± 0.50 ^{a}	17.60 ± 0.27 ^{bB}	0.001
	P value	< 0.01	< 0.01	

The variables presented a normal distribution and the data are represented by the mean ± standard deviation. Lowercase letters in the line indicate differences between substrates. Capital letters in the column indicate differences between collection ages. ANOVA was adopted at a 5% significance level.

The chemical composition of the material produced in hydroponics varies, as described by Shit (2019) [16], and several factors can influence this composition. It is believed that the chemical composition of the forage was also influenced by the composition of the substrate itself in this study, as the complete seedling, ungerminated corn grains, and the remaining substrate were part of the sample used for analysis.

DM was higher in forage grown in wood sawdust, whose substrate also had a DM content (94.37%) higher than that of elephant grass (93.80%), which may explain this result. Similarly, Campêlo et al. (2007) [4] obtained a higher DM content with the rice husk substrate than with elephant grass, and when evaluating the DM content of the roots of seedlings + substrates, they observed a lower content with elephant grass (19.62%) than with rice husk (41.12%).

The highest MM content was obtained in forage grown on elephant grass, which also had a higher ash content in its composition compared to wood sawdust (Table 1). This result corresponded to the development of seedlings because certain minerals promote their development. A well-developed root system provides greater nutrient capture and retention in the forage. Fonseca et al. (2021) [9] obtained 3.98% MM in hydroponic corn forage grown in ground Tifton hay and suggested that MM concentration is an indicator of plant nutrition.

The influence of the substrate on CP content has also been reported in other studies. In this study, although the substrate + seedlings were evaluated, and elephant grass resulted in a higher CP content, the levels obtained in both treatments are satisfactory to meet, in a complementary way, the nutritional requirements of ruminant animals and non-ruminant herbivores. In the production of hydroponic corn forage in elephant grass substrate, Santos et al. (2023) [5] reported a CP concentration of 11.48% at 13 days.

Elephant grass resulted in higher EE concentrations at 20 days of age ($P < 0.0$). The EE content in this study was higher than that previously reported for hydroponic corn forage. According to Shit (2019) [16], EE content is expected to increase in plants owing to an increase in lipid structures and chlorophyll as the plant grows. This was also observed in a study by Naik et al. (2012) [17], who described a difference in EE content on the day 5 (2.27%) compared to that on day 7 (3.49%). Holanda et al. (2021) [4] reported 1.4% EE in corn forage grown on rice husk substrates.

In the present study, fungal proliferation was noted in the seedbeds shortly after seed germination, and samples of corn seeds and substrates were analyzed. Fungi of the genera *Rhizopus* spp. and *Aspergillus* spp., both found in the corn seeds, were also found in wood sawdust, which proliferated in the forage produced. This may explain the high EE content observed in this study. According to Murphy (2001) [18], microorganisms such as fungi accumulate approximately 30%–80% of lipids in their biomass.

The concentrations of MM and CP increased with age, which has been reported in other studies. Almeida et al. (2021) [8] tested different collection ages and observed that CP decreased from day 10 (10.38%) to 20 (8.78%) but increased on day 25 (11.37%), and EE decreased from day 10 (2.10%) to 20 (1.45%), as observed in the present study. Ndaru et al. (2020) [15] observed that MM (2.37 *x* 2.60%) and CP (14.91 *x* 18.43%) increased from day 12 to 20. Manhães et al. (2011) [19] found 10.25% and 15.00% CP in forage corn harvested on days 10 and 17, respectively.

When evaluating the influence of substrates, a higher concentration of lignin was obtained in forage grown on wood sawdust ($P < 0.05$) at 13 days, while NDF, ADF, and cellulose were similar between treatments ($P > 0.05$). Wood sawdust also promoted a higher concentration of ADF and lignin ($P < 0.05$) at 20 days, while the NDF and cellulose concentrations were similar between the treatments ($P > 0.05$). When evaluating the collection age, only cellulose content was influenced, being higher in forage grown on elephant grass on day 20 ($P < 0.05$). None of the variables for forage grown in wood sawdust was influenced by collection age ($P > 0.05$) (Table 4).

Table 4 Fiber content of hydroponic corn forage grown in different substrates and harvested at different ages.

Collection age	Variables	Elephant grass substrate	Wood sawdust substrate	P value
13 days	Neutral detergent fiber	43.73 ± 5.14	41.57 ± 4.07	0.370
	Acid detergent fiber	18.68 ± 3.16	18.83 ± 2.43	0.918
	Cellulose	15.82 ± 2.49 [A]	14.05 ± 1.88	0.131
	Lignin	2.22 ± 0.83 [b]	4.32 ± 0.75 [a]	< 0.01

20 days	Neutral detergent fiber	41.07 ± 1.78	42.31 ± 4.71	0.501
	Acid detergent fiber	16.31 ± 1.10 [b]	19.33 ± 3.49 [a]	0.038
	Cellulose	13.77 ± 0.77 [B]	14.12 ± 2.17	0.674
	Lignin	1.51 ± 0.64 [b]	4.68 ± 2.11 [a]	< 0.01
	P value	< 0.01	>0.05	

The variables presented a normal distribution and the data are represented by the mean ± standard deviation. Lowercase letters in the line indicate differences between substrates. Capital letters in the column indicate differences between collection ages. ANOVA was adopted at a 5% significance level.

Rocha et al. (2014) [(20)] found that a higher value for both NDF (78.32%) and ADF (59.85%) on day 15 indicated that the high NDF content in the substrate (86.67%) may have promoted higher NDF content in forage. Müller et al. (2005) [(21)] suggested that there is a reduction in the NDF content of corn forage as seeding density increases. The smaller diameter of the plant stem, owing to competition for space when the seeding density is high, can result in smaller cell wall spacing and, consequently, reduced fiber content. This was observed in the studies by Almeida et al. (2021) [(8)] and de Rocha et al. (2014) [(20)] for NDF and ADF, which showed a reduction in these fractions with increasing harvest density.

The lignin content of forage grown on sawdust substrates was higher than that grown on elephant grass, regardless of the age at collection, which was probably influenced by the lignin content of the substrate. However, it is important to highlight that the lignin content obtained in both treatments was below the amount reported by Valadares Filho et al. (2020) [(22)] in other green forages commonly fed to ruminants, such as *Brachiaria decumbens* (5.35%), elephant grass (6.88%), and alfalfa (7.35%).

Thirteen days after sowing, there was a higher concentration of NFC in forage grown in wood sawdust ($P < 0.05$), while the TDN was similar between treatments ($P > 0.05$). There was no interference from the substrates for any of the variables on day 20 ($P > 0.05$). There was a reduction in the NFC concentration of forage produced on elephant grass with increasing collection age ($P < 0.05$) (Figure 1).

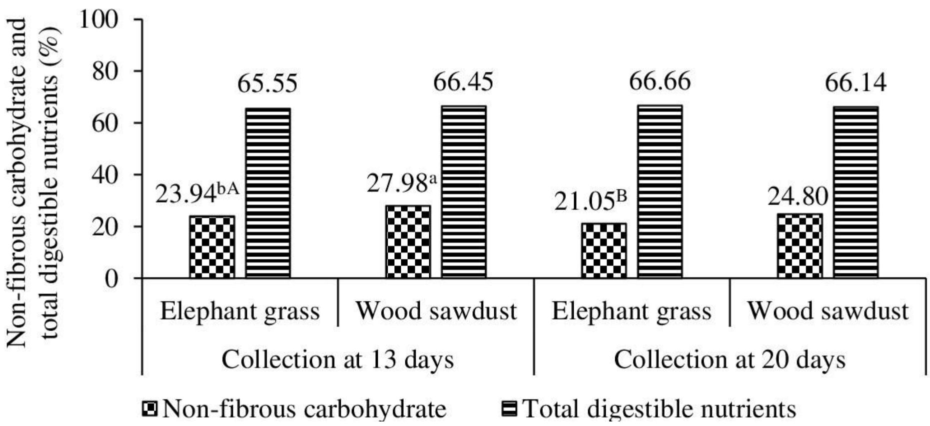

Figure 1 **Non-fibrous carbohydrate and total digestible nutrients from hydroponic corn forage grown in different substrates and harvested at different ages. Lowercase letters indicate differences between substrates and uppercase letters indicate differences between collection ages, by ANOVA at a 5% significance level.**

The lower NFC content observed in forage grown on elephant grass can be explained by the higher NDF and MM contents since the higher the CP, EE, MM, and NDF contents, the lower the amount of NFC. The NFC of food comprise a group of water-soluble non-starch polysaccharides, which are made up of fractions resistant to mammalian digestive enzymes and are not recovered in the NDF residue. Holanda et al. (2021) [(4)] obtained lower NFC (14.6%) because the ash (10.9%) and NDF (66.4%) contents were much higher, which inevitably influenced the NFC content.

4. Conclusion

Elephant grass substrate and collection 13 days after sowing promoted better results for the production of hydroponic forage, as well as for its nutritional composition.

Declaration of Conflict of Interest

We have no conflict of interest to declare

Author contributions

Research and writing (original draft): TB da Cruz-Neiva; JC Cerqueira; ESC dos Santos; RAL Almeida; EL Candeias-Oliveira; HS Silva; ALA Santana. *Resources*: LEC Andrade Sobrinho; Análise formal dos dados: KN de Oliveira; ALA Santana. *Methodology, Project management, Writing (review and editing):* ALA Santana

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