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Quality of hydroponic forage corn cultivated on different by-product substrates

Qualidade de forragem de milho hidropônico cultivado em diferentes substratos de subproduto

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Abstract

Hydroponic corn cultivation is an efficient, fast, and feasible alternative for periods of food scarcity; however, there is still little information on the qualitative and quantitative parameters of the produced biomass, especially with regard to substrates. This study aimed to evaluate the productive and qualitative aspects of hydroponic feed corn grown on different substrates with a cultivation period of 15 days. Four substrates were evaluated: 1) fermented whole açaí seeds, 2) crushed açaí seeds, 3) sugarcane bagasse, and 4) ground Tifton hay, with five replications under a randomized block design. Substrate temperature was monitored during the production period. After harvesting on day 15, roots length (RL), shoot length (SL), biomass dry matter content (BDM), dry biomass yield, forage dry mass productivity, crude protein (CP), and ash content were assessed. There was no correlation of growth period and substrate temperature. RL was not affected by substrates, BDM was lower in treatment 3, CP was not influenced, and ash content was higher in treatment 1. In general, the best development was observed in treatment 1 because of the absence of distinction regarding qualitative parameters (CP and ash) and higher granulometry of whole açaí seeds which affects mass density and substrate aeration, thus allowing higher dry biomass yield.

Keywords: açaí seed; agroindustry by-products; animal nutrition; forage production.

Resumo

O cultivo hidropônico de milho é uma alternativa eficiente, rápida e viável para períodos de escassez de alimentos; entretanto, ainda são poucas as informações sobre os parâmetros qualitativos e quantitativos da biomassa produzida, principalmente no que diz respeito aos substratos. Este trabalho teve como objetivo avaliar os aspectos produtivos e

qualitativos do milho hidropônico para ração cultivado em diferentes substratos com um período de cultivo de 15 dias. Quatro substratos foram avaliados: 1) sementes de açaí inteiras fermentadas, 2) sementes de açaí trituradas, 3) bagaço de cana-de-açúcar e 4) feno de Tifton moído, com cinco repetições em delineamento de blocos ao acaso. A temperatura do substrato foi monitorada durante o período de produção. Após a colheita, no dia 15, foram avaliados o comprimento das raízes (RL), o comprimento da parte aérea, o teor de matéria seca da biomassa (BDM), o rendimento da biomassa seca, a produtividade da massa seca da forragem, a proteína bruta (PB) e o teor de cinzas. Não houve correlação entre período de crescimento e temperatura do substrato. O RL não foi afetado pelos substratos, o BDM foi menor no tratamento 3, o PB não foi influenciado e o teor de cinzas foi maior no tratamento 1. Em geral, o melhor desenvolvimento foi observado no tratamento 1 devido à ausência de distinção quanto aos parâmetros qualitativos (PB e cinzas) e maior granulometria das sementes inteiras de açaí que afetam a densidade de massa e aeração do substrato, permitindo maior rendimento de biomassa seca.
Palavras-chave: caroço de açaí; coproduto da agroindústria; nutrição animal; produção de forragem.

Introduction

Livestock plays an important role in global food security; however, climate change has complicated the production of primary feed for livestock. Thus, new production alternatives are essential for this sector to remain competitive, profitable, and sustainable[1].

Hydroponic forage production refers to growing plants using a nutrient solution in a natural substrate, or even without substrate, during the initial growth period of forage plants[2,3], and this approach may be used when forage cannot be grown conventionally due to adverse conditions[4].

Hydroponic forage is a denomination given to a method of growing plants using a nutritive solution under natural substrates, or even no substrate, to the initial growth of the forage plants[5]. Piccolo et al.[6] observed that accumulation of nutrients from the solution along with seeds in the absence of a substrate, inducing plant death at the beginning of their development.

Using corn forage, Ndaru et al.[7] reported forage production of 12 kg m^{-2}, with moderate fiber content of 10% neutral detergent fiber (NFD) and 15% crude protein (CP) after 20 days of cultivation.

Numerous by-products of agriculture or agroindustry such as bagasse and whole or crushed seeds can be used as substrates in hydroponic cultivation to improve the sustainability of production systems, reduce environmental impacts, and increase use efficiency of natural resources. However, substrates for forage hydroponic production are typically included in the final biomass of animal feed, thus, apart from providing support and nutrients to plants, they must be consumable by animals.

The use of substrates in hydroponic forage production contributes to increasing the plants' dry mass content, thus, it may affect the nutritional value of the final product. Araújo et al.[8] observed higher productivity of hydroponic feed corn on substrates with smaller particles, and Campêlo et al.[9] observed lower CP content and higher dry mass productivity using rice hull, followed by higher NDF, ADF, and ash, compared to *Pennisetum* grass as a substrate.

The choice of substrate depends on its ability to support and supply nutrients to plants, as well as its effect as an ingredient in animal food. Thus, the aim of this study was to evaluate the productive and qualitative aspects of hydroponic feed corn production using different substrates.

Material and methods

The study was carried out in the experimental area of the Universidade Federal Rural da Amazônia (UFRA) on the Campus of Paragominas, Pará, Brazil. The experiment was conducted for 15 days in the dry season from June to December 2019, during which forage is typically produced. The local climate is classified as Aw (the predominant climate in this region is hot and humid tropical), according to Köppen, with an average temperature of 26.6 ºC and 1.805 mm annual rainfall, and the rainy season is from December to May.

The experimental design was carried out in a randomized block design using four substrates for hydroponic corn cultivation, with five replicates. The following substrates were used: 1) fermented whole açaí seeds, 2) crushed açaí seeds, 3) sugarcane bagasse, and 4) ground Tifton hay. Seed grains were collected from a 2018/19 crop.

The grains were considered industrial-use quality, with 99.98% purity. Impurities comprised burnt, broken, and/or damaged grains and dirt. The conventional industrial management of grains and their exposure to high temperatures in the drying process requires verification of germination ability. Thus, evaluation of seed physiological quality was assessed using four replicates of 50 seeds distributed on two sheets of germitest paper which was humidified with distilled water (three times the weight of dehydrated paper); a third paper sheet was used to cover the seeds which were then placed in a transparent bag.

Seeds were placed in a B.O.D. germinator with a constant temperature of 25 ºC for four days (10), which resulted in a germination rate of 88.5%. Considering purity (P) and germination (G) rates, the cultural value (CV) was 88.5%, using the equation

$$CV = (\%\ P \times \%\ G) / 100.$$

Fermentation of açaí seeds is necessary because of their high germination ability. For this, humid seeds were placed in bags and were exposed to natural irradiation for approximately 30 days, after which they were spread on the soil surface in a protected environment to dry.

Milling of açaí seeds and Tifton hay was performed using an electrical mill without a sieve. Sugarcane bagasse was obtained as an industrial by-product.

The experimental unit comprised a plot in a plane area of 1.0 × 0.5 m covered with plastic canvas. Substrates were applied in two 2-cm layers, i.e., one layer underneath and one above the seeds. Seed density was 2.5 kg m^{-2} of viable pure seeds applied to experimental units over the first substrate layer which was humidified.

Fertilization was applied twice, i.e., once before seeding and once three days before harvesting, using the commercial formulas 4-14-8 and 20-0-20 diluted in water and applied at 35 g m^{-2}.

Absorption capacity of each substrate was determined and adjusted according to Souza[11], which was based on initially applying water to 60% of the retention capacity of each substrate to 5, 4, 8, and 8 L m^{-2} to sugarcane bagasse, ground Tifton hay, crushed açaí seeds, and fermented whole açaí seeds. After shoot emergence, the moisture level was maintained through daily irrigation in the mornings and afternoons, according to the observed humidity conditions.

From the 3rd to 14th day of cultivation, the temperature of the cultivation substrate was evaluated using a mercury thermometer at three points of each substrate per plot at 1.00 p.m. as at this time, the highest incidence of solar radiation was observed, and the substrates were assumed to show increased temperature and high heat generation due to fermentation.

Fifteen days after seeding, the complete plants (roots and shoots) and substrate were collected for evaluation. Biomass yield and dry matter content were measured in samples collected with a sampler of 0.25 × 0.25 m in the center of each plot. The development of corn plants was evaluated using 10 units sampled at the center of each plot to measure shoot and root lengths.

Fresh biomass samples were weighed and placed in an oven with forced air circulation heated to 65 ºC for 72 h to record partial dry matter content (DM; #930.15). Dried biomass samples were ground in a mill (to 1 mm) for analysis of CP (CP; # 2001.11), according to AOAC (12), and ash content ass assessed using a muffle heated to 600 °C.

All variables were tested for normality using the Shapiro–Wilk test before further analysis at a significance level of $p < 0.05$, and any variable that deviated from normal distribution was transformed through the RANK procedure of SAS (SAS Inst. Inc., Cary, NC, USA). The PROC RANK statement with the NORMAL option was used to produce normalized transformed data. All data were analyzed using the MIXED procedure in SAS (SAS Inst. Inc.).

Results and discussion

The temperature of the cultivation substrates was adjusted to a negative quadratic curve, independent of the treatments (Figure 1).

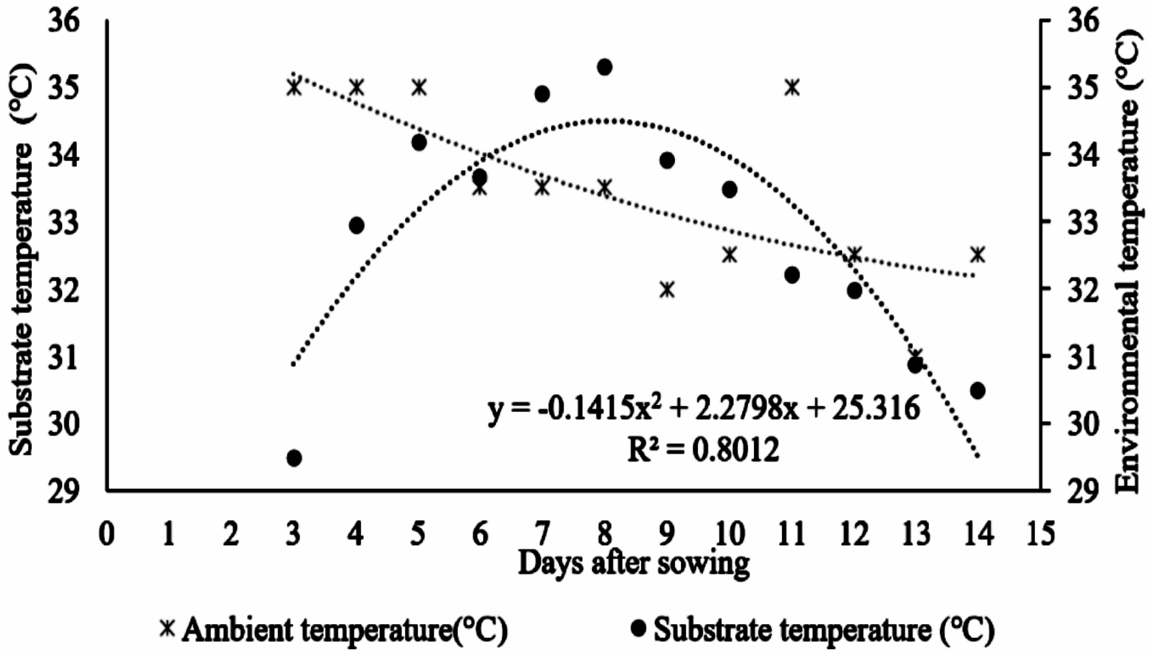

Figure 1. Cultivation substrate temperatures during the experimental period.

The peak temperature of the cultivation substrates occurred on the 8th day after seeding (Figure 1). The temperature increase may be a consequence of fermentation of non-germinated seeds or of the substrate once the substrate moisture produced anaerobic microenvironments. According to Biaggioni et al.[13], anaerobic respiration through degradation of carbohydrate molecules leads to the release of carbonic gas and production of heat. In addition, the data did not follow the pattern of ambient temperatures, particularly during the peak phase from the 6th to the 10th day, thus suggesting substrate or grain fermentation. Although there was no interaction effect between treatments and time on cultivation substrate temperature, average temperatures differed between treatments (Table 1).

Lower substrate temperatures were observed in fermented whole açaí seeds (Table 1), with the average being 0.89 ºC lower than that of other treatments. The physical form of whole açaí seeds with large particles and rough surface possibly allowed higher air circulation and gas exchange, resulting in lower temperatures.

Treatments had no effect on root length (Table 2); the lack of an effect may be explained by the growth phase, as root development depends less on external factors during the first days of development due to nutrient reserves contained in the seeds[14].

Table 1. Average temperatures of cultivation substrates

Treatments	Temperature (°C)
Fermented whole açaí seeds	32.11 ± 1.90 b
Ground Tifton hay	33.10 ± 1.86 a
Crushed açaí seeds	32.95 ± 1.87 a
Sugarcane bagasse	32.96 ± 2.12 a
p	< 0.0001
CV (%)	2.6

Averages followed by the same letter did not differ significantly according to Tukey's test at 5%.

Table 2. Root length (RL) and shoot length (SL) of hydroponic corn plants grown on different substrates for 15 days

Treatment	RL	SL
	cm	
Fermented whole açaí seeds	12.14 ± 4.30 a	14.16 ± 3.65 a
Ground Tifton hay	10.66 ± 2.34 a	11.02 ± 1.33 ab
Crushed açaí seeds	9.69 ± 2.76 a	11.77 ± 1.59 ab
Sugarcane bagasse	9.25 ± 3.41 a	9.73 ± 0.98 b
p	0.5326	0.0329
CV (%)	31.5	18.5

Averages followed by the same letter did not differ significantly according to Tukey's test at 5%.

Shoot length of plants grown on fermented whole açaí seeds was 45.52% longer compared to plants grown on sugarcane bagasse, which was not significantly different (p = 0.0329) from plants grown on ground Tifton hay and crushed açaí seeds (Table 2). This treatment represented the largest particle size, which possibly led to higher air circulation in the root environment, facilitating increased plant growth, whereas all other substrates showed a stronger tendency to logging. According to Santos(15), substrates with high porosity facilitate seedling emergence.

Sugarcane bagasse has been studied as a substrate for hydroponic forage cultivation with adequate results(16); however, it showed lower individual plant development, compared to ground Tifton hay and açaí seed treatments, although it had no effect on total forage dry matter productivity (Table 3).

Table 3. Biomass (forage + substrate) dry matter content (BDM), yield of dry biomass (YDB) and forage dry mass productivity (FDMP) of hydroponic corn grown on different substrates

Treatment	BDM %	YDB kg m^{-2}	FDMP kg m^{-2}
Fermented whole açaí seeds	30.04 ± 1.70 a	7.8 ± 0.84 a	1.92 ± 0.84 a
Ground Tifton hay	28.74 ± 4.63 a	3.65 ± 0.75 c	3.03 ± 0.75 a
Crushed açaí seeds	28.84 ± 6.97 a	5.57 ± 1.31 b	2.20 ± 1.31 a
Sugarcane bagasse	18.38 ± 2.05 b	3.21 ± 1.56 c	2.21 ± 1.56 a
p	0.0021	< 0.0001	0.4893
CV (%)	16.6	23	49.7

Averages followed by the same letter did not differ significantly according to Tukey's test at 5%

Biomass dry matter content and yield can be influenced by the physicochemical characteristics of the substrates, such as density and water retention capacity, in addition to decomposition speed. Pilau et al.[17] attributed higher dry mass of hydroponic forage cultivated on rice hull to larger amounts of the substrate used to provide the same layer thickness and lower decomposition speed as corn straw.

Total dry biomass differed between substrates; however, no effect on forage dry matter was observed (Table 3). Among several substrates evaluated to produce hydroponic corn forage[10], the dry matter of 85.8% from rice hull influenced the dry matter production of the produced biomass.

Considering the absence of treatment effects on forage productivity, the substrate choice must be based on dry biomass yield (Table 3), chemical and nutritional value for animal food, and production costs. However, CP content was similar among treatments (Table 4).

During early developmental stages, plants such as hydroponic corn, contain high levels of protein, thus increasing their nutritional value[18]. The observed CP values (Table 4) corroborated previously reported values of hydroponic feed corn[19], and satisfied the requirements of adult cattle[20]. Corn forage is thus superior to typical tropical forages used during the dry season.

Ash content differed between treatments (Table 4). Biomass produced with whole açaí seeds was superior to sugarcane bagasse, whereas no difference was observed between the other treatments. The higher ash content may indicate a favorable nutrient level in plants, probably explaining the increased shoot length (Table 2). Holanda[21] found higher ash content in plants with increasing physiological maturity, which resulted in increased root growth and thus facilitated increased uptake of minerals.

Table 4 . Crude protein (CP) and ash content of hydroponic corn biomass grown on different substrates

Treatment	CP	Ash
	%	
Fermented whole açaí seeds	11.17 ± 0.81 a	5.79 ± 2.32 a
Ground Tifton hay	12.02 ± 1.57 a	3.98 ± 0.95 ab
Crushed fermented açaí seeds	10.81± 1.40 a	3.51 ± 0.35 ab
Sugarcane bagasse	13.50 ± 4.36 a	2.95 ± 0.62 b
P	0.3467	0.0249
CV (%)	20.66	32.83

Averages followed by the same letter did not differ significantly according to Tukey's test at 5%.

All substrates examined here supported hydroponic forage production, and apart from ground Tifton hay, all substrates were agro-industrial by-products, which is important considering sustainability. Although its quantitative performance was lower, sugarcane bagasse may also be a feasible alternative for this cultivation technique, particularly for farmers located near sugarcane production facilities.

The use of a substrate depends on the costs of logistics and handling. Treatments with açaí seeds showed higher dry biomass yield (Table 3), which thus represents an attractive alternative, mainly in Amazon areas where large açaí extraction facilities are located. This substrate has already been used for vegetable and fruit cultivation, mainly by familiar agriculture[22], but it remains an otherwise unmarketable by-product with low handling and logistic effort.

Further evaluations of nutritional aspects, such as dry matter digestibility and gases emitted by ruminants (including greenhouse gases) are necessary for accurate decisions. In addition, it should be examined whether the larger particle size of açaí whole seeds may result in lower forage digestibility due to its lower specific surface area.

Biomass, which comprises forage and substrates of hydroponic corn production, was quantitatively influenced by the substrate, even though productivity and quality of forage plants were little affected. This suggests that hydroponic forage production is useful for utilization of by-products as an alternative to animal feed production. Thus, more research is required on substrate production management, use in animal feed, and economic viability to ensure a desirable cost/benefit ratio, as such methods can be applied throughout the year, regardless of climatic conditions.

Conclusion

Agroindustrial co-products as substrates showed potential for use in hydroponic feed corn production. Açaí seeds stood out among the tested substrates as it produced higher yield with regard to aerial biomass production.

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Conflict of interests

The authors declare no conflict of interests.

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