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Production Performance and Chemical Composition of Various Hydroponic Fodder Species

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A B S T R A C T

The traditional agricultural system is highly dependent on the soil and the natural environment. It is encountering significant challenges from climate change, soil degradation, and water scarcity. Hydroponic fodder production offers as an alternative solution to traditional agricultural system of fodder cultivation which does not rely on soil and can be produced in controlled environment while yielding highly nutritious fodder. This study assesses biomass production, plant height, primary root length, chlorophyll index, nutritional content and economic feasibility of five hydroponic fodder species which includes maize (*Zea mays*), wheat (*Triticum aestivum*), oat (*Avena sativa*), sorghum (*Sorghum bicolor*), and cowpea (*Vigna unguiculata*). The research was conducted at Dr. Purnendu Gain field laboratory and Animal Husbandry laboratory at Khulna University, Bangladesh. Experimental design was completely randomized design (CRD). There were five repetition and, in each repetitions consisted of four replications for each species. Seeds were carefully selected, prepared, and grown in a controlled environment. It was harvested at 11th day after germination. Results indicated that oat consistently achieved the highest biomass yield, peaking at 1254.22g ± 249.98 from 250 g seeds on day 11, followed by cowpea at 1045.22 g ± 71.57 from same quantity of seeds. Oat also maintained the highest plant height reaching up to 19.81 cm ± 1.34 by day 11. Maize showed the longest root length, measuring of 28.59 cm ± 0.120. Cowpea demonstrated the highest chlorophyll levels across all days. Wheat was proved to be the most cost-effective option. Highest dry matter (DM), crude protein (CP), crude fiber (CF), ether extract (EE), total ash (TA) and nitrogen-free extract (NFE) was found in wheat (26.62% ± 2.91), cowpea (25.80% ± 0.48), oat (19.31% ± 1.62), maize (3.59% ± 0.17), cowpea (9.61% ± 0.36) and maize (54.15% ± 2.48), respectively. The results demonstrated the potential of hydroponic fodder production as a viable, sustainable solution for livestock farming, particularly in regions where traditional fodder cultivation is constrained.

1. Introduction

Population estimates from the UN indicate that there will be 10.1 billion people on the globe in 2100, up from 7.7 billion people today, and 9.3 billion people in 2050 (Lee, 2011). Migration and reclassification put agriculture in competition with thriving urban areas for soil, water, and labor, and require it to fight climate change on all fronts maintaining biodiversity, preserving habitats, and producing more food with fewer workers and less land. It seems that agriculture, as the hub of the food chain, is facing a significant challenge. Despite the thousands of acres treated with chemical pesticides and fertilizers that are no longer suitable for farming because of soil

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degradation, water scarcity, and climate change, open-field agriculture is still widely practiced worldwide (Zárate, 2014). The majority of today's farming practices rely on soil and water, making them very susceptible to disasters. Therefore, it is vital that current economic policies of farming systems must be changed (Gashgari et al., 2018). Several climate changes impacts; declining soil fertility, water availability, and competition between cereal crops and fodder have made this situation even worse (El-Morsy et al., 2013).

Researchers have focused their emphasis on investigating more effective alternative methods of producing fodder in considering the limitations associated with the traditional method and the substantial gap between the availability and demand for green fodder (Girma & Gebremariam, 2018; Naik et al., 2015). Hydroponics is one of the soilless culture methods. The Greek terms "hydro" (meaning water) and "ponos" (meaning work) are the origin of the term "hydroponics" (Ani & Gopalakirishnan, 2020). Hydroponic forage is grown without the need of soil and with water. Nutrient-rich liquids can be used in greenhouses for brief periods of time. The feed, which consists of roots, seeds, and plants, resembles a mat and is likely 20 to 30 cm tall. Animals find it to be extremely tasty, easily digested, and nutrient-dense. When hydroponic fodder is used, milk production increases by 8–13%. In locations where the production of conventional green fodder is restricted, this is the ideal substitute technique for use with inexpensive resources for dairy animals (Naik et al., 2015).

A viable substitute technique for sustainable livestock farming is hydroponic fodder production (Girma & Gebremariam, 2019). A several varieties of fodder crops, including barley, oat, wheat, sorghum, alfalfa, cowpea, and maize, can be grown using hydroponic technology (Al-Karaki & Al-Hashimi, 2012; Brown et al., 2018; Farghaly et al., 2019; Guerrero-Cervantes et al., 2016; Kide et al., 2015;). Cereal green fodder is cultivated hydroponically over a period of 7-9 days (Farghaly et al., 2019; Fazaeli et al., 2011; Wang et al., 2019). The choice of hydroponic fodder varieties is dependent upon the particular geographic and agroclimatic conditions, in addition to the availability of seeds. Furthermore, the economic viability of hydroponic fodder production can be facilitated through the incorporation of wheat (*Triticum aestivum* L.) (Guerrero-Cervantes et al., 2016; Tayade & Chavan, 2018).

Hydroponic fodder production has become popular for its advantages in enhancing livestock well-being. Hydroponics fodder is known for its added palatability, digestibility and valuable nutritional value, which contributes to the well-being of livestock (Naik et al., 2015). Hydroponic growing systems can achieve a larger harvest of livestock feed, all the while utilizing substantially less space when compared with traditional methods (Schoenian, 2013). Fodder seeds are grown using tap water or nutrient-enriched solutions without soil which makes hydroponic fodder a feasible alternative for fresh feed (Bakshi et al., 2017). In terms of ether extract, nitrogen-free extracts, organic content, and crude protein, hydroponic fodder performs better than conventional non-leguminous fodder. However, the total digestible nutrient content, metabolizable energy, and gross energy all decrease during sprouting. This results from the plant's energy intake during respiration (Ajmi et al., 2009; Fazaeli et al., 2011). This study aims to estimate the comparative performance of five different hydroponic fodders by assessing their biomass production, height, primary root length, chlorophyll level, their nutritional content through proximate analysis, and determining their recurring production costs.

2. Materials and Methods

2.1. Site selection

The research took place at the Dr. Purnendu Gain Field Laboratory and Animal Husbandry Laboratory of the Agrotechnology Discipline at Khulna University. The research unit is situated on 22º80' N and 89º53' E latitude and longitude.

2.2. Design of the study

The research was conducted using a completely randomized design (CRD). The five species examined including maize (*Zea mays*), wheat (Triticum aestivum), oat (*Avena sativa*), sorghum (*Sorghum bicolor*) and cowpea (*Vigna unguiculata*) crops. Each species represented as a treatment group. No control group was considered as the research focus on comparative analysis among the treatment groups. There were five repetitions. Each repetition had four replications for each treatment group (species).

2.3. Collection and selection of seeds

Fodder seeds were collected from local markets of same local variety for each species. To ensure high-quality hydroponic fodder production, good quality seeds free from damage and disease were carefully selected.

2.4. Preparation of growing area

The growing area and trays were thoroughly cleaned and disinfected by using 0.3 % chlorhexidine gluconate + 3% cetrimide solution then again rinsed to establish an aseptic environment. This proactive measure effectively prevented the proliferation of bacteria or disease-causing organisms. Also, proper drainage system was ensured to avoid the issue of waterlogging. Arrangement of the research unit of hydroponic fodder growing area is shown in Figure 1. Photographs of oat hydroponic fodder on harvest day, sorghum hydroponic fodder on harvest day and measurements of chlorophyll levels of oat hydroponic fodder are shown in Figures 2, 3 and 4, respectively.

Figure 1. Arrangement of the research unit of hydroponic fodder growing area

Figure 2. Oat hydroponic fodder on the day of harvest

Figure 3. Sorghum hydroponic fodder on the day of harvest

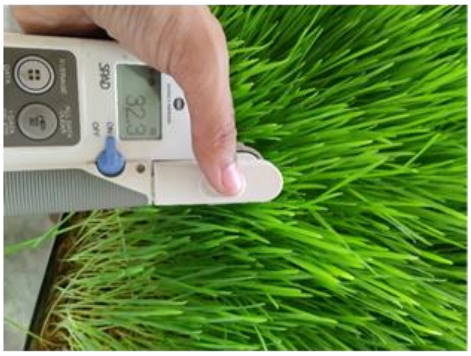

Figure 4. Measuring of chlorophyll level of oat hydroponic fodder

2.5. Preparation and placement of seeds

The seeds were rinsed under running water to remove impurities and debris. After thorough rinsing, the seeds were soaked in water for 12 hours to initiate germination. After draining the water, the seeds were kept in a gunny bag for 24 hours in a dark environment until they sprouted. For each species and each replication, 250 grams of seeds were taken throughout the five repetitions of the experiment. The seeds were evenly spread on the trays after they sprouted. The trays were placed in the rack which held the trays in a 1-inch tilted position to facilitate excess water drainage.

2.6. Uniformity of the environment

The research was conducted in winter season of Bangladesh. The average ambient temperature ranged from 21.02°C ± 0.10 to 25.91°C ± 0.36 during the study. Temperature was recorded four times for each day. Recorded temperatures during the study period are shown in Table 1. After germination, seeds were spread on the trays and trays were covered with cloth and curtain was also used to maintain a dark environment for the first three days. From day four to harvest both natural and artificial lighting was provided. Two 15watt white color LED lights were used in the research unit and was lit for 12 hours each day (6AM-6PM).

Table 1. Average temperatures (°C) throughout the experiment

Day	Repetition 1 (December)	Repetition 2 (December - January)	Repetition 3 (February)	Repetition 4 (February)	Repetition 5 (March)
1	20.50	22.50	21.30	26.75	24.75
2	20.40	21.50	23.15	26.50	24.60
3	21.00	22.25	23.30	26.25	24.00
4	21.25	23.50	24.25	23.60	26.00
5	21.00	22.25	23.45	24.25	24.65
6	21.10	22.75	22.00	25.25	26.65
7	21.10	23.75	24.50	25.05	27.10
8	21.40	22.00	23.85	24.25	26.60
9	21.40	20.15	24.25	25.20	26.25
10	21.00	17.25	25.65	25.30	27.00
11	21.10	18.00	25.05	26.25	27.45
MEAN	21.02	21.45	23.70	25.33	25.91
SEM	0.10	0.64	0.38	0.31	0.36

Mitigation of potential biasness was implemented and the randomization of the experimental setup was ensured by a systematic shuffling of the trays containing each species throughout the duration of the study. By periodically rearranging the trays, variations in factors such as light exposure, temperature, humidity, and other microclimate were evenly distributed across all treatment groups (species). Artificial lighting during daytime was also provided along with natural lighting to ensure uniformity. Exposure to natural light was also controlled with the help of curtain to eliminate excess heating and dehydration as it can damage the seeds or hydroponic fodder.

2.7. Supplementation of water

Seeds were watered regularly 3-4 times daily manually. Only tap water was used from the same source. No nutrient solution was use with tap water.

2.8. Harvesting

The hydroponic fodder was harvested at 11th day after germination.

2.9 Cleaning and repeating

The growing area and trays were cleaned thoroughly to eliminate any residue. The process was repeated by soaking and preparing new seeds then again spreading them evenly on the trays to initiate a new cycle of hydroponic fodder production. The experiment was repeated five times with four replications for each treatment group.

2.10. Biomass yield

Biomass of different hydroponic green fodder was measured using a weighing balance. The quantification and record keeping of biomass production took place everyday morning before watering. Seeds weight after they were germinated (Germination weight) was also recorded on the very first day before spreading the seeds on the trays.

2.11. Plant height

Three plants were randomly chosen from each tray for measurement of height. Every plant was measured for height from the tray floor to the top leaf, and the average height of the plants was noted.

2.12. Primary root length

Three plants were selected at random from every tray to measure the height of their primary roots. Root length of various hydroponic fodder species was measured between day 4 and day 11.

2.13. Chlorophyll index

The chlorophyll levels of various hydroponic fodder species were assessed using an SPAD meter from day 7 to day 11.

2.14. Determination and comparison of production cost

The production costs associated with each hydroponic fodder species were analyzed and determined. The hydroponic fodder with the highest economic feasibility and profitability was determined, considering both biomass yield and production costs based on per kg seed for comparison.

2.15. Proximate analysis

The chemical composition of dried fodder samples was determined at the Animal Husbandry Laboratory, Agrotechnology Discipline, Khulna University, Khulna. The dry matter (DM), crude protein (CP), crude fiber (CF), ether extract (EE) and total ash (TA) contents of hydroponic fodder samples were estimated according to AOAC (1990). The samples used in this analysis contained the full part of the hydroponic fodder including the leafy portion, seeds and roots.

2.16. Data analysis

For analysis, a one-way ANOVA was employed. Descriptive statistical tools, including the calculation of averages and standard errors were applied using the tabular technique. The analysis was conducted utilizing SPSS software (version 26.0).

3. Results

3.1. Biomass yield

Biomass yields of different hydroponic fodder species measured over 11 days are shown in Table 2. Germination weights from 250g seed showed that cowpea (514.72g ± 4.95) had the highest values, followed by oat (399.89g ± 5.38), wheat (363.81g ± 1.62), maize (337.28g ± 3.34) and sorghum (332.20g ± 4.12) where the mean difference was significant ($p<0.001$). Oat (360.40g ± 64.10) and cowpea (344.15g ± 38.15) had the highest biomass yields on day 2 followed by wheat (277.95g ± 13.48) and sorghum (272.47g ± 15.73) while maize (229.03g ± 24.08) had the lowest biomass. Oat and cowpea had significantly higher biomass yields compared to sorghum and maize at day 5. Biomass of wheat did not significantly differ from any of the other species on the same day. Oat (602.57g ± 55.09) had the highest biomass yield on day 5, followed by cowpea (562.86g ± 61.86), wheat (446.93g ± 21.78), maize (397.21g ± 25.34) while sorghum (384.77g ± 21.65) had the lowest biomass yield. Oat (1240.89g ± 281.56) continued to show the highest yield on day 10, with cowpea (800.93g ± 86.65), wheat (704.54g ± 45.99), maize (694.18g ± 61.96) were followed and sorghum (664.02g ± 42.68) showed lowest yield. Oat had a significantly higher yield compared to all other species during day 8 to 10. Cowpea, wheat, maize, and sorghum during this time did not show a significant difference from each other for biomass yield. Oat (1254.22g ± 249.98) and cowpea (1045.22g ± 71.57) had the highest biomass yields at day 11. Wheat (732.85g ± 46.78), sorghum (720.44g ± 53.58) were followed and maize (707.79g ± 56.81) had the lowest yield.

Table 2. Biomass yields (g) of different species of hydroponic fodders from 250g of seeds

Day	Sorghum (*Sorghum bicolor*)	Cowpea (*Vigna unguiculata*)	Wheat (*Triticum aestivum*)	Maize (*Zea mays*)	Oat (*Avena sativa*)	F-value	Sig.
Germination	$332.20^{d} \pm 4.12$	$514.72^{a} \pm 4.95$	$363.81^{c} \pm 1.62$	$337.28^{d} \pm 3.34$	$399.89^{b} \pm 5.38$	410.31	***
2	$272.47^{ab} \pm 15.73$	$344.15^{a} \pm 38.15$	$277.95^{ab} \pm 13.48$	$229.03^{b} \pm 24.08$	$360.40^{a} \pm 64.10$	2.94	**
3	$347.54^{abc} \pm 21.49$	$472.63^{a} \pm 54.01$	$323.21^{bc} \pm 14.36$	$290.89^{c} \pm 27.42$	$433.81^{ab} \pm 63.81$	4.23	**
4	$370.13^{b} \pm 22.75$	$548.25^{a} \pm 68.83$	$405.88^{ab} \pm 24.07$	$348.79^{b} \pm 29.75$	$558.69^{a} \pm 89.65$	3.82	*
5	$384.77^{c} \pm 21.65$	$562.86^{ab} \pm 61.86$	$446.93^{bc} \pm 21.78$	$397.21^{c} \pm 25.34$	$602.57^{a} \pm 55.09$	4.40	**
6	$424.74^{c} \pm 24.56$	$605.85^{b} \pm 63.68$	$513.97^{bc} \pm 33.29$	$459.83^{bc} \pm 31.04$	$816.84^{a} \pm 144.87$	5.48	***
7	$465.06^{c} \pm 27.44$	$676.91^{b} \pm 75.10$	$567.15^{bc} \pm 34.85$	$523.50^{bc} \pm 34.78$	$942.29^{a} \pm 162.69$	5.89	***
8	$531.96^{b} \pm 32.62$	$733.86^{b} \pm 83.53$	$630.47^{b} \pm 39.76$	$584.62^{b} \pm 40.36$	$1099.35^{a} \pm 214.29$	5.77	***
9	$595.79^{b} \pm 38.36$	$773.59^{b} \pm 91.13$	$679.10^{b} \pm 42.07$	$637.89^{b} \pm 46.30$	$1168.87^{a} \pm 224.25$	4.877	**

10	664.02^{b} ± 42.68	800.93^{b} ± 86.65	704.54^{b} ± 45.99	694.18^{b} ± 61.96	1240.89^{a} ± 281.56	4.29	**
11	720.44^{b} ± 53.58	1045.22^{a} ± 71.57	732.85^{b} ± 46.78	707.79^{b} ± 56.81	1254.22^{a} ± 249.98	8.07	***

*** p < 0.001, ** p < 0.01, * p < 0.05; Means with uncommon superscripts in a row differed significantly (p<0.05).

3.2. Plant height

Height of different hydroponic fodder species was measured during day 4 to day 11 and are shown in Table 3. On day 4, wheat (3.23 cm ± 0.62) and oat (3.23 cm ± 1.22) had the highest height while sorghum (1.40 cm ± 0.15) showed lowest height. Wheat and oat significantly differed from sorghum, while the heights of maize, and cowpea were not significantly different. On day 11, oat (19.81 cm ± 1.34) followed by maize (19.04 cm ± 1.40) consistently remained the tallest among all the days and cowpea (16.02 cm ± 0.69), wheat (13.97 cm ± 0.81) and sorghum (13.74 cm ± 0.54) showed the shorter height throughout the cultivation period. Oat significantly differed from sorghum, cowpea, and wheat, while the height of maize was not significantly different with oat on day 8, 9, 10 and 11. Statistical analysis unveiled significant difference in height among different species, with varying degrees of significance recorded across different days (***p < 0.001, **p < 0.01, *p < 0.05).

Table 3. Heights (cm) of different species of hydroponic fodders at different stage of growth (d)

Day	Sorghum (*Sorghum bicolor*)	Cowpea (*Vigna unguiculata*)	Wheat (*Triticum aestivum*)	Maize (*Zea mays*)	Oat (*Avena sativa*)	F-value	Significance
4	1.40^{b} ± 0.15	2.23^{ab} ± 0.23	3.23^{a} ± 0.62	2.51^{ab} ± 0.27	3.23^{a} ± 1.22	3.271	**
5	2.26^{c} ± 0.33	3.37^{bc} ± 0.39	5.23^{ab} ± 0.87	4.91^{ab} ± 0.50	6.06^{a} ± 2	4.819	**
6	4.68^{b} ± 0.48	6.59^{b} ± 0.71	7.10^{b} ± 0.83	6.96^{b} ± 0.43	10.17^{a} ± 1.17	4.654	**
7	6.01^{c} ± 0.55	8.54^{b} ± 0.75	8.62^{b} ± 0.81	8.99^{b} ± 0.44	12.32^{a} ± 0.65	6.146	***
8	8.37^{c} ± 0.31	10.78^{b} ± 0.78	10.47^{bc} ± 0.66	12.30^{ab} ± 0.68	13.67^{a} ± 0.35	6.614	***
9	10.51^{c} ± 0.50	12.07^{bc} ± 0.74	12.12^{bc} ± 0.67	14.26^{ab} ± 0.68	16.32^{a} ± 1.43	6.347	***
10	11.96^{b} ± 0.34	13.56^{b} ± 0.68	13.22^{b} ± 0.75	17.31^{a} ± 1.17	18.06^{a} ± 1.38	8.635	***
11	13.74^{b} ± 0.54	16.02^{b} ± 0.69	13.97^{b} ± 0.81	19.04^{a} ± 1.40	19.81^{a} ± 1.34	7.459	***

*** p < 0.001, ** p < 0.01,; Means with uncommon superscripts in a row differed significantly (p<0.05).

3.3. Root length

Root length of different hydroponic fodder species was measured during day 6 to day 11 and are shown in Table 4. Maize (7.90 cm ± 0.12) had the longest root on day 6, followed by oat (3.99 cm ± 0.11), cowpea (3.61 cm ± 0.05), sorghum (2.74 cm ± 0.09), and wheat (2.59 cm ± 0.05). Root length of maize was significantly differed from all other species. Maize (28.59 cm ± 0.12) had the longest root length at day 11 which was consistently from day 6 to day 11 after germination, followed by oat (12.60 cm ± 0.06), wheat (8.18 cm ± 0.05), sorghum (6.30 cm ± 0.04), and cowpea (6.09 cm ± 0.05). Shortest root length was found in cowpea from day 9 to day 11 after germination. Significant difference was not found between sorghum and cowpea but they were significantly different from wheat, maize and oat at the day of harvest.

Table 4. Average primary root length (cm) of different species of hydroponic fodders at different stage of growth (d)

Day	Sorghum (*Sorghum bicolor*)	Cowpea (*Vigna unguiculata*)	Wheat (*Triticum aestivum*)	Maize (*Zea mays*)	Oat (*Avena sativa*)	F-value	Level of significance
6	$2.74^{d} \pm 0.09$	$3.61^{c} \pm 0.05$	$2.59^{d} \pm 0.05$	$7.90^{a} \pm 0.12$	$3.99^{b} \pm 0.11$	728.3	***
7	$4.47^{c} \pm 0.12$	$4.30^{c} \pm 0.06$	$3.34^{d} \pm 0.04$	$8.40^{a} \pm 0.11$	$5.82^{b} \pm 0.10$	451.6	***
8	$5.54^{c} \pm 0.12$	$4.94^{d} \pm 0.06$	$4.29^{e} \pm 0.12$	$10.10^{a} \pm 0.10$	$7.26^{b} \pm 0.03$	478.4	***
9	$5.81^{c} \pm 0.13$	$5.25^{d} \pm 0.09$	$5.27^{d} \pm 0.11$	$19.25^{a} \pm 0.09$	$9.61^{b} \pm 0.06$	2936.8	***
10	$6.13^{d} \pm 0.07$	$5.58^{e} \pm 0.07$	$7.07^{c} \pm 0.09$	$19.55^{a} \pm 0.08$	$12.16^{b} \pm 0.09$	5037.2	***
11	$6.30^{d} \pm 0.04$	$6.09^{d} \pm 0.05$	$8.18^{c} \pm 0.05$	$28.59^{a} \pm 0.12$	$12.60^{b} \pm 0.06$	18780.5	***

*** $p < 0.001$, Means with uncommon superscripts in a row differed significantly ($p<0.05$).

3.4. Chlorophyll index (SPAD reading)

Chlorophyll level of different hydroponic fodder species was measured during day 7 to day 11 which are shown in Table 5. During day 7 cowpea (36.12 ± 0.44) had the highest chlorophyll level, followed by oat (31.34 ± 0.45), wheat (28.82 ± 0.54), maize (28.59 ± 0.41), and sorghum (24.38 ± 0.29). Chlorophyll level of cowpea was significantly different from that of all other species. Chlorophyll level of cowpea remained consistently high throughout the experiment and also at the day of harvest, where sorghum (21.81 ± 0.24) consistently had the lowest chlorophyll content throughout the days when it was recorded. Chlorophyll level of cowpea differed significantly from all other species.

Table 5. Chlorophyll level of different species of hydroponic fodders at different stage of growth (d)

Day	Sorghum (*Sorghum bicolor*)	Cowpea (*Vigna unguiculata*)	Wheat (*Triticum aestivum*)	Maize (*Zea mays*)	Oat (*Avena sativa*)	F-value	Level of significance
7	$24.38^{d} \pm 0.29$	$36.12^{a} \pm 0.44$	$28.82^{c} \pm 0.54$	$28.59^{c} \pm 0.41$	$31.34^{b} \pm 0.45$	106.8	***
8	$23.63^{d} \pm 0.13$	$34.73^{a} \pm 0.75$	$32.82^{b} \pm 0.43$	$29.55^{c} \pm 0.27$	$32.47^{b} \pm 0.44$	80.5	***
9	$23.01^{d} \pm 0.15$	$39.03^{a} \pm 0.63$	$29.70^{b} \pm 0.37$	$26.20^{c} \pm 0.34$	$29.47^{b} \pm 0.19$	214.3	***
10	$22.02^{e} \pm 0.10$	$40.20^{a} \pm 0.47$	$33.77^{b} \pm 0.39$	$24.33^{d} \pm 0.34$	$31.11^{c} \pm 0.30$	436.9	***
11	$21.81^{e} \pm 0.24$	$39.17^{a} \pm 0.69$	31.96^{b} b± 0.43	$26.31^{d} \pm 0.30$	$28.64^{c} \pm 0.07$	203.1	***

*** $p < 0.001$, Means with uncommon superscripts in a row differed significantly ($p<0.05$).

3.5. Cost analysis

Production costs per kilogram (in Bangladeshi Taka, BDT, 1 USD is equivalent to 118 BDT) for different hydroponic fodder species is shown in Table 6. Sorghum (51.16 BDT/kg ± 3.90) had the highest production cost, closely followed by cowpea (50.52 BDT/kg ± 3.99) followed by Oat (39.25 BDT/kg ± 8.60) which had a moderate production cost, while maize (33.01 BDT/kg ± 2.22) showed a lower production cost. Wheat (21.12 BDT/kg ± 1.17) had the lowest production cost among the hydroponic fodder species. Sorghum and cowpea were not significantly different from each other for production costs. Wheat had a significantly less production cost compared to all other species.

Table 6. Production cost of different hydroponic fodder species

Species	Production cost (BDT#. kg^{-1})
Sorghum (*Sorghum bicolor*)	51.16^{a} ± 3.90
Cowpea (*Vigna unguiculata*)	50.52^{a} ± 3.99
Wheat (*Triticum aestivum*)	21.12^{c} ± 1.17
Maize (*Zea mays*)	33.01^{b} ± 2.22
Oat (*Avena sativa*)	39.25^{ab} ± 8.60
F-value	14.957
Level of significance	***

*** p < 0.001# 1 USD is equivalent to 118 BDT (approx.)

3.6. Chemical composition

Chemical composition of different hydroponic fodder species is presented in Table 7. Wheat fodder (26.62% ± 2.91) had the highest dry matter (DM) content, with cowpea (9.87% ± 0.22) having the lowest DM content. Wheat DM was significantly different from sorghum, cowpea, oat, and maize. Cowpea (25.80% ± 0.48) showed highest crude protein (CP) content, where maize (11.38% ± 0.26) had the lowest CP content. Cowpea was found significantly different from sorghum, oat, wheat, and maize for their CP contents. In term of crude fiber, oat (19.31% ± 1.62) had the highest content, and wheat (8.00% ± 0.07) had the lowest CF content. Regarding ether extract (EE), maize (3.59% ± 0.17) had the highest content, where cowpea (2.39% ± 0.13) had the lowest EE content. Maize was significantly different from sorghum, oat, wheat, and cowpea for EE content. Cowpea (9.61% ± 0.36) had the highest total ash (TA) content, where oat (3.39% ± 0.06) showed lowest TA content. Cowpea was noticed significantly different from sorghum, oat, wheat, and maize. In case of nitrogen-free extract (NFE), maize (54.15% ± 2.48) showed highest result, followed by sorghum (53.05% ± 0.92), oat (47.11% ± 2.41) and wheat (39.76% ± 2.59), while cowpea (35.26% ± 0.92) had the lowest NFE content.

Table 7. Chemical composition (%) of different species of hydroponic fodders

Fodder species	Chemical composition (%)					
	Dry matter (DM)	Crude Protein (CP)	Crude Fiber (CF)	Ether extract (EE)	Total ash (TA)	Nitrogen Free Extract (NFE)
Sorghum	18.11^{b} ± 0.69	13.12^{b} ± 0.37	8.16^{b} ± 0.10	3.13^{b} ± 0.17	4.42^{b} ± 0.22	53.05^{c} ± 0.92
Cowpea	9.87^{bc} ± 0.22	25.80^{a} ± 0.48	17.08^{bc} ± 0.23	2.39^{bc} ± 0.13	9.61^{a} ± 0.36	35.26^{b} ± 0.92
Wheat	26.62^{a} ± 2.91	18.78b^{c} ± 0.30	8.00^{b} ± 0.07	3.35^{c} ± 0.05	3.49^{bc} ± 0.13	39.76^{b} ± 2.59
Maize	17.52^{b} ± 2.51	11.38^{bd} ± 0.26	9.75^{b} ± 0.10	3.59^{a} ± 0.17	3.61^{bd} ± 0.17	54.15^{a} ± 2.48
Oat	13.20^{b} ± 1.47	13.80^{b} ± 0.52	19.31^{a} ± 1.62	3.18^{d} ± 0.10	3.39^{be} ± 0.06	47.11^{bc} ± 2.41
Total	16.86 ± 1.29	16.60 ± 1.05	12.38 ± 0.94	3.12 ± 0.10	5.01 ± 0.48	46.04 ± 1.66
F-value	11.701	225.646	64.809	11.274	146.998	18.853
Significance	***	***	***	***	***	***

*** p<0.001; Means with uncommon superscripts in a row differed significantly (p<0.05).

3.7. Correlation matrix

Table 8 presents correlations between various parameters related to plant growth and development, including germination weight, biomass yield, height, root length, and chlorophyll level, all measured on the 11th day after germination. Table contains a Pearson correlation coefficient, indicating the strength and direction of the linear relationship between two variables. Chlorophyll level strongly correlates with both germination weight and biomass yield, suggesting that plants with higher chlorophyll content tend to have heavier seeds and greater biomass. However, there is a significant negative correlation between germination weight and root length (-0.398**), suggesting that heavier seeds may produce plants with shorter roots.

Table 8. Correlation matrix (r) among germination weight, biomass weight, height, root length and chlorophyll levels of hydroponic fodders at day 11.

	Germination wt. (g)	**Biomass wt. at day 11 (g)**	**Height at day 11 (cm)**	**Root length at day 11 (cm)**	**Chlorophyll level at day 11**
Germination Wt. (g)	1				
Biomass yield at day 11 (g)	0.525**	1			
Height at day 11 (cm)	0.115	0.112	1		
Root length at day 11 (cm)	-0.398**	-0.204	0.511**	1	
Chlorophyll level at day 11	0.869**	0.381*	0.005	-0.293	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

4. Discussion

4.1. Biomass yields

In an experiment it was noticed that biomass yield from 500g seed of red sorghum was 900g ± 53.24 harvested at 7th day after germination which is higher than our current findings (Akinmutimi et al., 2022). In case of wheat Bari et al. (2022) revealed that, biomass yield was 6.27kg ± 0.15 from 450g of seed harvested on day 8 which was also higher than our current findings. Another study revealed that 3.5kg of wheat fodder can be hydroponically grown from 1kg of seed when harvested at 8th day which is higher than current study (Rahman et al., 2020). Another study noticed biomass yield of maize hydroponic fodder at 8th day was 8.00kg ± 0.36 from 500g seed which does not correspond to the present study and present study showed lower biomass yield in maize hydroponic fodder (Kide et al., 2015). Maize production in hydroponic technology was found lower in the current investigation than some other studies (Rahman et al., 2020; Upreti et al., 2022). Hiller and Perry (1969) observed that, from 100g of oat seed 550g of oat hydroponic fodder can be produced when harvested at 6th day which is higher than present study. According to Upreti et al. (2022), when 1 kg oat seeds were used it was found that it produced 7.96 kg of hydroponically grown oat fodder at 11th day which is higher than present findings. In another different investigation oat was found to produce 3.02 kg to 3.35 kg of hydroponically grown fodder from 1 kg of seed at 8th day which is higher than the current study. Cowpea hydroponic fodder found to 4.12 kg to 4.29 kg at 8th day which is also higher present finding (Jolad et al., 2018). In a separate experiment, researchers maintained a temperature of 24°C and a relative humidity of 50-73% to examine the output of barley fodder. They utilized growing trays measuring 45 cm x 25 cm x 8 cm and hydroponic fodder was harvested 9th day. The yield of barley fodder was 25.0 kg/m2 in fresh weight and 4.1 kg/m2 in dry weight (Al-Karaki, 2011). Gebremedhin (2015) illustrated, barley and maize had fresh yield values of 52.9 kg/m2 and 47.1 kg/m2, respectively. According to Shit (2019), different hydroponic fodder production methods may result in variations in biomass yield. Some factors such as design of hydroponic trays and the types of nutrient solutions used can affect growth and yield of the fodder. No nutrient solution was used in the present study, that may be the cause for lower biomass production than that of other researchers. Biomass yield of hydroponic fodder can also be influenced by environmental conditions such as humidity, temperature, and light intensity (Shit, 2019). Assefa et al. (2020) noticed that, seed rate can also affect the biomass yield. Some experiments suggest in situations with limited sunlight, artificial or supplemental lighting is utilized to compensate for the insufficient light needed for photosynthesis. The use of additional lighting has significantly increased plant productivity (Hao et al., 2018; Rahman et al., 2021).

4.2. Plant height

A study found plant height of maize, oat and wheat were 27.77 cm, 27.11 cm and 25.03 cm respectively which is higher than our findings (Upreti et al., 2022). In another investigation by Murthy et al. (2017) revealed that, at 5th day height of maize, sorghum and cowpea were 18.1 cm, 10.8 cm and 25.33 cm respectively which is higher than the current findings. According to Bari et al. (2022), height of wheat hydroponic fodder at 11th day was 14.10 cm ± 0.51 which is also higher than present investigation. Growth of plants can be affected by the production methods employed in hydroponic systems and based on the use of nutrient solutions. Use of nutrient solution instead of tap water as nutrient source can significantly increase plant height (Dung et al., 2010).

4.3. Root length

Bari et al. (2022) illustrated that, the root lengths on day 6, day 7, and day 8 were 7.10cm ± 0.22, 8.56cm ± 0.21, and 9.72cm ± 0.32, correspondingly, indicating higher root length compared to the results of the present investigation. Another study demonstrated root lengths of yellow maize on the sixth, seventh, and eighth days were 13.9cm ± 0.181, 14.5cm ± 0.331 and 17.5cm ± 0.26, respectively, which exceeded the outcomes of the present study. In case of sorghum (Jowar) recorded root lengths were 16.6cm ± 0.38, 17.9cm ± 0.22 and 20.3cm ± 0.35 in day 6, day 7 and day 8 respectively which is significantly higher than the current findings (Jemimah et al., 2018). Jolad et al. (2018) found that root lengths at 8th day of fodder maize, wheat, oat and fodder cowpea were found 22.71 cm, 15.70 cm, 15.67 cm and 18.57 cm, respectively which is higher than the present investigation. Difference in the root length may be attributed to several factors including the use of tap water instead of nutrient solution, pH level of the supplied water, temperature, humidity, available oxygen, type of hydroponic system implemented.

4.4. Chlorophyll index (SPAD reading)

Experiment conducted by Jolad et al. (2020) showed hydroponic fodder of maize, wheat, oat, and cowpea at seventh day chlorophyll index was found to be 32.18, 31.89, 31.84, and 38.11, respectively. On the eighth day, the chlorophyll index for fodder maize, wheat, oat, and fodder cowpea were recorded as 33.78, 32.80, 32.76, and 39.10, respectively. Chlorophyll index at 7th day for fodder maze fodder, wheat and fodder cowpea was higher than the current findings but oat is in accordance with the present study. During eighth day, wheat and oat were in accordance with current findings but in case of fodder maize and fodder cowpea it was higher. The chlorophyll levels in hydroponic fodder vary due to factors such as light intensity and quality, nutrient availability, water quality, environmental stresses, and genetic differences among plant species.

4.5. Cost analysis

Bari et al. (2022) noticed, cost of production of per kg wheat hydroponic fodder was 4.97BDT. ± 0.12 (1 USD is equivalent to 118 BDT) which lower than our findings. Another investigation revealed that, hydroponic maize fodder, oat fodder and wheat fodder required total cost of 20.64, 24.67 and 18.76 Nepalese rupee for one kg of hydroponic fodder production, respectively, which is lower than our current findings (Upreti et al., 2022). Another experiment demonstrated the costs to produce 1kg hydroponic fodder for yellow maize, cowpea, sorghum were 3.20, 10.90, 7.90 Indian Rupee, respectively, which is significantly lower than the present study (Jemimah et al., 2018). According to Jolad et al. (2020), costs of fodder maize, wheat, oat, and cowpea were 22.14, 40.14, 52.14, 72.14 Indian Rupee per kg seed and cost of fodder maize was found similar to our study but wheat, oat and cowpea fodder showed lower production cost in the current study. The cost difference can be caused by high costing of the seed and lower biomass yield.

4.6. Chemical composition

Bari et al. (2022) noticed that, when harvested at day eight CP, EE, CF, NFE and ash content per 100g DM for wheat were 19.83g ± 0.35, 2.70g ± 0.03, 4.68g ± 0.03, 69.82g ± 0.33, 2.96g ± 0.01, respectively, where CP content was similar to our findings but EE, CF, Ash contents were higher in the present study and NFE content was lower. Another study demonstrated that when harvested at 11th day, DM and CP contents for maize hydroponic fodder were 12.55% ± 2.05 and 12.51% ± 0.3, respectively. In case of oat, it was 14.13% ± 0.71 and 13.96% ± 2.08, respectively, and in case of wheat it was 14.49% ± 1.18 and 16.16% ± 1.59. Crude protein content of the oat is in accordance with our findings but CP content of maize was lower and for wheat it was higher in our study and DM contents of oat was lower and for maize and wheat was higher in the present investigation (Upreti et al., 2022). According to Jemimah et al. (2018), CP, CF, EE, TA and NFE of yellow maize hydroponic fodder were 10.55%, 5.51%, 6.42%, 1.80% and 77.52%, respectively, where CP, CF and TA contents of the present study were higher and EE and NFE were lower. In case of cowpea those components were 27.84%, 6.51 %, 1.93%, 4.88% and 58.84%, respectively, and CP, EE and TA content were higher in the current findings but CP and NFE contents were lower. For sorghum CP, CF, EE, TA and NFE were, 13.27% 13.39%, 4.99%, 2.98% and 65.37% where CP content were similar to our findings but TA content in the present study was higher but CF, EE and NFE were lower.

Jolad et al. (2020) showed that, total protein contents of fodder maize, wheat, oat and fodder cowpea were 14.58%, 12.75%, 12.38% and 16.06%, respectively, and current study found higher CP content in wheat, oat, cowpea but lower in maize hydroponic fodder. Crude fat was found 7.20%, 6.11% and 6.07% for fodder maize, wheat and oat, respectively. Crude fat of all of species of hydroponic fodder was higher than the current study. In a separate study conducted on maize hydroponic fodder found that CP, EE, CF, NFE and TA contents were 13.57%, 3.49%, 14.07%, 66.72% and 3.84%, respectively, when harvested at seventh day (Naik et al., 2015). Present study found higher EE content and lower CP, CF, NFE and TA contents than that of Naik et al. (2015). In another observation maize hydroponic fodder had lower DM, ash and higher CP, EE, CF, NFE contents than the present study. In their observation by Kide et al. (2015), it was found that DM, CP, EE, CF, NFE and Ash were 18.25% ± 0.12, 14.56% ± 0.29, 4.67% ± 0.19, 10.00% ± 0.17, 68.47% ± 1.63 and 2.83% ± 0.03, respectively. In a different study it was observed that DM, CP, EE, CF, TA and NFE contents were higher in case of maize when harvested at 14th day. In case of wheat, CP and CF contents were similar but it had increased NFE content and lower DM, EE and TA contents than the present findings. Average DM, CP, EE, CF, TA and NFE contents of maize were 20.15% ± 0.40, 17.43% ± 0.24, 4.85% ± 0.05, 18.39% ± 0.12, 3.94% ± 0.01, 55.39% ± 0.019, respectively, and wheat had 14.64% ± 0.16, 18.94% ± 0.01, 3.13% ± 0.06, 8.10% ± 0.22, 3.38% ± 0.09 and 66.46% ± 0.18, respectively (Mahale et al., 2020). It was demonstrated by Akinmutimi et al. (2022) that, significantly higher DM with higher CP and ash contents, lower EE content and similar CF and NFE content in maize hydroponic fodder which was allowed to grow to 7 days. In case of red sorghum that DM was significantly higher, lower CP contents, higher EE, CF and ash contents and similar NFE contents. They found average DM, CP, EE, CF, NFE, ash contents for maize hydroponic fodder were 87.63%, 12.84%, 3.14%, 9.65%, 57.35%, 4.67% and for red sorghum hydroponic fodder were 88.09%, 15.33%, 3.36%, 11.55%, 53.05%, 4.81%, respectively. Hillier & Perry (1969) observed higher DM, NFE and EE contents with lower CP, CF and ash contents in hydroponically grown oat fodder with growing period of 6 days. Average DM, CP, CF, NFE, EE and ash contents were 89.7%, 12.3%, 10.1%, 69.5%, 4.9% and 3.2%, respectively. The proximate composition of hydroponic fodder may vary due to factors such as implemented hydroponic techniques, composition of nutrient solution, plant species and varieties, environmental conditions, water quality, growth stage, stress factors and harvesting time.

5. Conclusion

This study highlights feasibility of hydroponic technology when implemented on various fodder species in tropical region like Bangladesh. This technology can be utilized if traditional agricultural system faces significant challenges. The comparative analysis of biomass yield, plant height, root length, and chlorophyll content of maize, wheat, oat, sorghum, and cowpea indicate that hydroponic cultivation can effectively be used for fodder cultivation and higher nutrient contents of these hydroponic fodder can supply sufficient nutrients. Oat and cowpea demonstrated high biomass production. This experiment represents potential of hydroponic technology in the tropical climate of southwestern region of Bangladesh and it can be used to mitigate fodder shortages and improve livestock nutrition sustainability. For supplementation of nutrients to the animals, it can also be combined with cultivated fodder. It offers a promising solution to meet the rising demand for animal feed and supply them with nutrients. The adoption of this technology could benefit farmers in increasing agricultural productivity and sustainability in fodder production when there is a lack of cultivable land or traditional agricultural system face challenges.

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