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Changes in morphology, nutrient content and production costs of hydroponic wheat as fodder

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ABSTRACT

This study was conducted to investigate the changes in morphology, biomass yield, chemical composition and production cost of Hydroponic Wheat Fodder (HWF) with the advancement of growing days. The HWF was cultivated at low cost sprouting house at the Bangladesh Agricultural University (BAU) Dairy Farm, Mymensingh, Bangladesh. Firstly, wheat grains were collected, washed and then soaked in tap water for 12 h. Thereafter, grains were wrapped with a gunny bag for 24 h for germination. Then, grains were spread out in trays and irrigated using tap water up to 8^{th} day morning. Biomass yield, morphological, nutritional parameters and cost of production were determined daily from each of the eight batches (day, 0 to 8) in the sprouting house. An increasing trend was seen in biomass yield, plant height, root length and root number of HWF with the days of advancement and found highest on 8^{th} day ($p=0.000$). Biomass yield was increased 6 times during this 8 days cycle. On the contrary, a decreasing trend was observed in cost of production (0-5^{th} day) and found lowest (BDT. 5.00) value in day 6^{th} -8^{th} ($p < 0.001$). A strong positive ($r=0.891$-0.989) correlation exists between biomass yield and morphological features ($p < 0.001$). Whereas, cost of production negatively ($r=-0.857$--0.946) correlated with biomass yield and morphological parameters ($p < 0.001$). The dry matter content of HWF reduced ($p < 0.001$) gradually from day 0 to 8. The crude protein, ether extracts and minerals (calcium, phosphorus and magnesium) content of HWF increased positively from day 0 to 8 but nitrogen-free-extracts and organic matter declined ($p < 0.001$) gradually. However, morphology, biomass yield, chemical composition and production cost of fodder were similar between the days of 7 to 8. Finally, farmers might grow HWF up to 7-8 days as a new source of livestock feed.

Introduction

Green fodder is a natural diet for livestock (Jemimah *et al.*, 2018) and sustainable farming largely depends on regular supply of quality green fodder (Naik *et al.*, 2012; Naik *et al.*, 2014). Productivity of dairy animals are negatively affected due to serious crisis of green fodder supply worldwide (Jemimah *et al.*, 2018). In Bangladesh, animal feeds and fodder shortage has been considered as a major constraint for livestock production (Uddin and Dhar, 2018). Only 0.1% cultivable land is used for fodder production in Bangladesh due high pressure of cereal grains demand. Moreover, 1% cultivation land is reducing every year due to the pressure from population growth and rapid urbanization (BBS, 2014; Bari *et al.*, 2020). This situation become more critical due to severe climate change, deterioration of fertile soil and water resource, competition between fodder and cereal crops (El-Morsy *et al.*, 2013). On the hand,

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intensive high yielding animal production system increases nutrient requirement for the animals that rises green fodder demand rapidly as the ruminant animals cannot always be dependent on cereal grains like that of mono-gastric animals (Girma and Gebremariam, 2018). These shortage of green fodder leads to substantial production loss of ruminant animals (Kide *et al*., 2015). Therefore, considering the constraints in conventional method of fodder production and realizing the huge gap between demand and supply of green fodder, researchers have been given their attention to explore alternative ways of fodder production in a better way (Naik *et al.,* 2015; Girma and Gebremariam, 2018). Hydroponic is an alternative and one of the latest technologies for growing green fodder and has significance in regions where the production of green fodder is limited (Omar *et al*., 2012; Bari *et al*., 2020).

Hydroponic fodder is produced from grains that are germinated and grown under acceptable growing conditions inside the special growing room (hydroponic machine or low cost greenhouse system) for a short period of time (Sneath and McIntosh, 2003; Naik *et al*., 2015). Hydroponic technique is free of chemicals such as insecticides, herbicides, fungicides, and artificial growth promoters (Naik *et al.,* 2015; Girma and Gebremariam, 2018). Hydroponic green fodder has highly palatable sprouts and plant height varies from 15 - 20 cm that can be easily produced through soil-less germination of cereal grains (FAO, 2001). Grains sprouting activities involve several modifications viz. carbohydrates are transformed into sugar, proteins converted into essential amino acids, and fats are altered into essential fatty acids (Farghaly *et al*., 2019). These alterations increased with the intensifications of enzyme levels (Shipard, 2005). Hydroponically sprouted grain raises the amount of minerals, vitamins, crude protein, ash and crude fiber, and decreases the phytic acid level in fodder (Morgan *et al*., 1992, Farghaly *et al*., 2019). According to Girma and Gebremariam (2018), enzymes can also remove other anti-nutritional factors during germination. Germination and sprouting also neutralize the cereal grain inhibitors and improve the digestion facilitating enzymes profile (Shipard, 2005). The most important aspect of hydroponic fodder production is that one kilogram of grains can produce 6 to 10 kg of fresh green fodder within one week at any time of the year and weather condition (Gebremedhin, 2015). Though it seems like growing a lot of feed with the increase in fresh weight, but there is a consequent decrease in the DM content compared with the initial grain (Islam *et al*., 2016). Fresh biomass yield and nutrient, especially DM content of the crops are critical for effective production of hydroponics fodder (Naik *et al*., 2015). The fresh yield and DM content of the hydroponic fodders are influenced by the several factors viz. crop types, seed quality, seed rate, light, growing period, water quality, pH, used nutrient solution, temperature, humidity, clean and hygienic condition of the sprouting house etc. (Dung *et al*., 2010b; Fazaeli *et al*., 2011; Naik, 2012b; Naik *et al.,* 2015). According to Salo (2019), great diversity exists in the benefit or loss of DM over 8-10 days of sprouting period ranged from 10 per cent loss to 15 per cent gain.

Fresh hydroponic fodder are produced from barley, corn, oat, cow peas, sorghum and wheat grains (Naik et al., 2015, Girma and Gebremariam, 2018; Salo, 2019). Wheat is an important serial grain in Bangladesh and it is possible to use this grain for hydroponic fodder production. But it is very obligatory to understand the biomass yield, morphology and nutrient change pattern and cost involvement in hydroponic fodder production system for efficient fodder production. Research was conducted on nutrient change pattern of maize (Naik *et al*., 2012), barley (Akbad *et al*., 2014), cowpea (Naik *et al*., 2016), sorghum (Sriagtula *et al*., 2021) and wheat (kantale et al., 2017) in hydroponic machine system. Kantale et al. (2017) compared the nutrient composition of different days old hydroponic wheat fodder produced in hydroponic machine system. But there is no research works came into attention to the authors regarding the morphology, nutrient change pattern and production costs involvement with the advancement of growth of hydroponic wheat sprouts in low cost housing system and their correlations. But detail study of biomass yield, morphology and nutrient change pattern, and economics of such an innovative production system should carefully be scrutinized before taking production decision (Islam *et al*., 2016; Al-Karaki and Al-Hashimi, 2012). The present study was therefore carried out to assess changes in plant height, root number and length, yield of biomass, nutrient content and cost of production of the hydroponic wheat fodder with the days of sprouting.

Materials and Methods

Production of hydroponic fodder

Green wheat sprout (Triticum aestivum) was produced in a hydroponic fodder production unit of Research Dairy Farm, Department of Dairy Science, Bangladesh Agricultural University (BAU), Mymensingh-2202, Bangladesh (24º43′46.5′′N, 90º25′22.8″E). Hydroponic wheat fodder was produced in a low-cost type hydroponic sprouting house (21 × 12 × 10 ft^3) for one month and per day production aptitude was 50 kg fresh fodder. This housing system consists of locally available insulating materials i.e. polythene, gunny bag etc., wooden shelves, electric fan, light, thermometer, hygrometer and manual sprinklers. The sprouting unit had two wooden shelves (20 × 1 × 5 ft^3) with each a capacity of up to 53 hydroponic aluminum trays (30×12×1.5 $inch^3$ /tray). Growing trays (105) had a seed capacity of 450 g, and 15-20 small pores for excess water drainage. For irrigation, hand sprinklers and tap water were used. Total 8 batches of hydroponic fodder of different stages (from seed to day 8 sprout) were produced continuously in the hydroponic production unit. Every day one batch (day 0) enters into the process and one batch (day 8) was harvested.

Wheat seeds (BARI Gom 26) were collected from the Bangladesh Agricultural Development Corporation BADC, Mymensingh sadar, Mymensingh-2200, Bangladesh. Collected seeds were then sun dried to reduce its moisture at 12-14% for better storage and germination. Planting trays were washed with caustic detergent and disinfected with bleaching powder, and then sun dried before starting a new batch. Every day, weighed seeds (around 6.75 kg; 450g for each of the 15 trays of one batch) were cleaned from debris and other foreign materials through washing by tap water. Later, seeds were soaked in fresh water for 12 hours. Then, all water has been drained out and grains were hanging in a perforated bucket for 1 h (breathing time) to become externally water-free. For germination, grains were wrapped with a cotton cloth and filled into the gunny bag and, about 85% germination took place within 24 hours. Then, germinated and non-germinated seeds were transplanted and sprayed on sterilized aluminum trays. Water was given through sprinklers to the wheat sprout up to 8^{th} day morning at intervals of 3 hours for keeping it moist all the time. Care was also taken to avoid accumulation of water to prevent growth of the fungus. The trays were switched from one row to another each day and from one side to the other to complement the 8-day period from germination state to harvesting time. Everyday random samples (from five different positions of 3 random trays for every batch) have been obtained from trays containing germinated seed from day 1 until day 8 sprouts and the sample was collected from 10 successive batches.

Measurement of morphological parameters

Plant height was measured from the base of the plant to tip of the plant and root length was measured from the base of the plant to the tip of the root. Both the plant height and root length were measured in centimeter (cm) using a measuring scale by keeping on glass. Root numbers of the sample sprouts were counted individually. Biomass yield of fodder was measured using a weighing balance (RFL electric weighing balance, SS straight, LA-111×100, 100 kg, Bangladesh).

Chemical analysis

Randomly the representative fodder samples (300 g of each day) from each batch were collected, weighed and sun dried for 2-3 days. After proper sun drying the samples were oven-dried at a temperature of 105ºC for 24 hours for the determination of dry matter (DM). Then, the dried samples were grounded at 8000 rpm by lab mill type grinding machine (Christry and Norris Limited, Process Engineers Chelmsford, England). Thereafter, the ground samples were kept into polythene bag, labeled and stored for further chemical analysis. Processed samples were analyzed for organic matter (OM), crude protein (CP, N× 6.25), crude fiber (CF), ether extract (EE), nitrogen-free-extract (NFE) and ash by using standard procedures (AOAC, 2005). These proximate components were analyzed at Animal Science laboratory, Department of Animal Science, BAU, Mymensingh-2202, Bangladesh. All the grounded feed samples were analyzed twice and mean values were recorded.

Digestion of the sample and minerals analysis

Calcium, magnesium, and phosphorus content in hydroponic wheat fodder were determined at the Post-graduate Laboratory of Agricultural Chemistry, Department of Agricultural Chemistry, BAU, Mymensingh-2202, Bangladesh. About 1 g wheat fodder ground sample was digested in a block digester system (VELP Scientific, Model DK 6, Italy) as described by Singh and Parowan (1999). In this, the required sample was digested with 10 mL di-acid mixture (96% conc. HNO_3 and 60% $HClO_4$ at 2:1) and was heated at 180-200°C until white fumes were evolved. Calcium and magnesium concentrations of fodder samples were determined by EDTA titrimetric method where Na_2EDTA was used as chelating agent and the pH was 12. Phosphorus content was measured calorimetrically using the stannous chloride method (Jackson, 1973). The intensity of color was measured within 10-15 minutes by T60 UV-Vis spectrophotometer (PG Instruments Limited, Model TG-60U, China) and the wavelength was 660 nm.

Economic analysis

Total cost of production per month of hydroponic wheat fodder was calculated including all cost items viz. land, seed, labor, electricity (for light, fan, water etc.), depreciation cost @ 10% on house construction and 20% on tray preparation cost and others, detergent and miscellaneous costs (Table-1). Cost of production for 1 kg hydroponic wheat fodder at different days was calculated through considering the days of production cycle, number of batch continuing each day, yield per batch and cost of each batch at different days in the production cycle.

Table 1: Cost of Production of Hydroponic wheat fodder

Items	**Cost (BDT.)**
Capital Expenditure	
Land 360 sq. ft.	43,000/-
House construction (252 sq. ft.) with shelves @ BDT. 300/ sq. ft.	75,000/-
Trays preparation 105 @ BDT. 150/P	15,700/-
Miscellaneous	10,000/-
Recurring Expenditure (Monthly)	
Land cost (per month rent of 360 sq. ft.) @ BDT. 36000/- per acre land rent cost	25/-
Wheat seed 202.5 kg @ BDT.18/Kg	3,645/-
Labour 72 hours @ BDT. 25/hour or 6000/month	1,800/-
Electricity (around 39 unit)@ BDT.5.14/unit	200/-
Depreciation cost @ 10% on house construction and 20% on tray preparation cost and others	517/-
Detergent cost	100/-
Miscellaneous	25/-
Monthly production cost	***6312/-***

N.B. Continuously 8 batch of hydroponic fodder (of above mentioned days) was produced. Here, we consider price of land BDT. 50000/decimal (435.6 Sq. ft.).

Statistical analysis

One way analysis of variance (ANOVA) was performed using Minitab 17 software (Minitab Limited, Brandon Court, Coventry, UK). The mean difference among the treatments was achieved by Tukey's HSD test. The relationships between morphological parameters, biomass yield, production cost, and nutrient parameters were calculated by Pearson's correlations. Multiple regression analysis of biomass yield was performed by considering the morphological parameters e.g. plant height, root number and root length as predictors. Multiple regression analysis was done where nutrient content and cost of production considered as responses, and biomass yield and morphological parameters thought as predictors.

Result and Discussion

Morphological characteristics, biomass yield and production cost

The changes in morphological features (root number, root length and plant height) and biomass yield of hydroponic wheat fodder (HWF) at different days of growth are tabulated in Table 2. All the morphological parameters of wheat fodder increased with the advancement of production days. The root numbers on day 8 (7.98) was found higher than other days (0 -7.9) of the given period. Root numbers of HWF gradually increased ($p < 0.001$) from day 1 to day 5 but after that it was remained statistically alike ($p > 0.05$) up to the 8th day of production. An increasing trend was also observed in root length of HWF with the days of production and it reached at maximum level at 8th day (9.7 cm). But, root length in day 7 and 8 varied non-significantly. In this study, roots germination and visibility require 1 day which is earlier than the other types of seed. This is consistent with the findings of Naik et al. (2015) who reported that maize and cowpea seeds germination in hydroponic condition starts after 1 or 2 days and roots were clearly visible after 2 or 3 days of sowing.

The height of the plant was significantly increased from day 1 to 8 ($p < 0.001$) and ≈ 2 cm height increased daily. Average 14 cm height was found at 8th day of production which was 12 cm higher than that of the day 1. This finding agrees with Naik and Singh (2013) and Naik et al. (2014). Plant height generally depends on types of grain and the hydroponics fodder appearances like a mat of 11-30 cm height consisting of germinated seeds embedded in their white roots and green shoots after end of the germination period of about 8-days (Snow *et al*., 2008; Dung *et al*., 2010b; Naik *et al*., 2011; Naik *et al*., 2014).

Table 2: Morphological and biomass yield changes pattern of hydroponic wheat fodder

Day	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	*P*-Value
Root Number	0.00^{e} ±0.00	1.80^{d} ±0.64	4.47^{c} ±0.77	5.10^{c} ±0.58	6.02^{b} ±0.68	7.42^{a} ±0.70	7.49^{a} ±0.72	7.89^{a} ±0.58	7.98^{a} ±0.68	0.000
Root Length (cm)	0.00^{i} ±0.00	0.79^{h} ±0.06	1.21^{g} ±0.19	3.10^{f} ±0.08	5.32^{e} ±0.23	6.23^{d} ±0.15	7.10^{c} ±0.22	8.56^{ab} ±0.21	9.72^{a} ±0.32	0.000
Plant Height (cm)	0.00^{i} ±0.00	0.99^{h} ±0.05	2.32^{g} ±0.37	4.20^{f} ±0.11	6.80^{e} ±0.29	8.47^{d} ±0.29	10.34^{c} ±0.54	11.98^{b} ±0.66	14.10^{a} ±0.51	0.000
Biomass yield (kg)	1.00^{i} ±0.00	1.85^{gh} ±0.09	2.14^{g} ±0.07	2.70^{f} ±0.07	3.29^{e} ±0.14	4.19^{d} ±0.11	5.26^{c} ±0.16	5.98^{ab} ±0.10	6.27^{a} ±0.15	0.000

N. B. Biomass yield at day 0 indicates the weight of the seed only. Mean values in a row with uncommon superscript differed significantly.

Biomass yield of hydroponic fodder was increased gradually from day 0 to 8. Result revealed that significant differences ($p < 0.001$) existed in biomass yield of HWF in terms of growing days but yield was remained statistically similar ($p > 0.05$) between 7 to 8 days of production. About 6.3 kg hydroponic wheat fodder was recorded at day 8 from 1 kg of wheat grain sowing at day 0. The higher amount of biomass yield at 8th day of sprouting may be due to greater height in plant, root length and root number of that day (Table 2) which is in accordance with the findings of Islam *et al*. (2016). The present findings were highly collaborated with Morgan *et al*. (1992) and Bautista (2002) who observed a significant variation in dry weight (DW) and wet weight (WW) of the hydroponic fodder. Fresh weight was increased 1.72 times after 1 day sprouting compared to the original dry seed weight and it continued up to around 6 folds after 7 days of sprouting (Peer and Lesson, 1985) which is in line with our findings. Kantale *et al*. (2017) found 7.12 kg biomass yield at 8th day in machine grown hydroponic wheat fodder which is higher compared to our current findings and this may be due to use of hi-tech hydroponic machine compared to manual cultivation of hydroponic fodder with least cost sprout housing system and use of nutrient solution instead of only tap water. Average green fodder yield ranged from 5 -7 kg per each kg of barley grain at 6 to 8 day of production (Naik *et al*., 2015). Generally, biomass yield of hydroponic fodder influenced by several factors e.g. the crop types, harvesting time, seed type and quality, seed rate, water quality, nutrient solution used or not, types of greenhouse, pH, irrigation frequencies, temperature, humidity, light, production period etc. (Sneath and McIntosh, 2003; Dung *et al*., 2010b; Fazaeli *et al*., 2012). Considering the yield of fresh fodder obtained per unit of grain seed, the conversion ratio of production might be varied from 4 to 8 times of seed (Morgan *et al*., 1992; Peer and Lesson, 1985b).

Production cost of HWF in different days is demonstrated in Table 3. Result revealed that the production cost of per kg HWF was lowest at 8th day (BDT 5.00) which was statistically different from day 1 to day 5 ($p < 0.001$) and similar with 6 and 7th day growing costs. The price of per kg wheat seed was BDT. 18 at day 0. This production cost is similar to the findings of Naik *et al*. (2012b) who mentioned that cost of production of per kg hydroponic maize fodder in India was 4-4.5 Rs. (4.6-5.2 in BDT, according to Bangladesh Bank). According to Kide *et al*. (2015), cost of production generally influenced by the seeds quality and sprouting house conditions. The seed cost showed 90 per cent of the total cost of hydroponic fodder rising (Al-Karaki and Al-Momani, 2011).

Correlation among morphological parameters, biomass yield and cost of production are presented in Table 4. It was observed that a strong positive ($p < 0.01$) correlation exists among all the morphological parameters of HWF with biomass yield. The highest r- value was recorded for the correlations between root length and plant height (r= 0.995). On the contrary, cost of HWF production was strongly but negatively ($p < 0.01$) correlated with biomass yield, plant height, root length and root numbers of HWF.

Multiple regression analysis showed that 1 cm increase in plant height of every sprout obtained from 1 kg seed, increased biomass yield by 0.42 kg ($p < 0.001$). Whereas each unit increase in root length and root numbers increases the biomass yield by 0.08 and 0.04 unit, respectively ($p > 0.05$). Again, each unit of root and biomass yield, reduced production cost of HWF BDT by 1.3 and 1.8 unit, respectively (Table 5).

Table 3: Cost of production of hydroponic wheat fodder in different days

Items	Day wise cost of production of hydroponic wheat fodder (BDT)									
	Day 0	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**	**Day 8**	**p-Value**
Land cost (BDT.)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	-
Wheat seed (BDT.)	121.5	121.5	121.5	121.5	121.5	121.5	121.5	121.5	121.5	-
Labor (BDT.)	0	7.5	15	22.5	30	37.5	45	52.5	60	-
Electricity (BDT.)	0	0.8	1.6	2.4	3.2	4	4.8	5.6	6.4	-
Depreciation Cost (BDT.)	0	2.2	4.4	6.6	8.8	11	13.2	15.4	17.6	-
Detergent cost (BDT.)	0	0.4	0.8	1.2	1.6	2	2.4	2.8	3.2	-
Miscellaneous (BDT.)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	-
Total Cost of batches	121.5	132.6	143.7	154.8	165.9	177	188.1	199.2	210.3	-
Yield per batch (kg)	6.75^{i} ±0.00	12.47^{gh} ±0.63	14.46^{g} ±0.49	18.21^{f} ±0.47	22.21^{e} ±0.95	28.26^{d} ±0.73	35.49^{c} ±1.09	40.39^{ab} ±0.69	42.37^{a} ±1.01	0.000
Cost of Production/ kg (BDT)	18.00^{a} ±0.00	10.66^{b} ±0.54	9.95^{c} ±0.34	8.51^{d} ±0.21	7.48^{e} ±0.34	6.27^{f} ±0.16	5.11^{g} ±0.17	4.94^{g} ±0.08	4.97^{g} ±0.12	0.000

N.B. Continuously 8 batches of hydroponic fodder (of above mentioned days) was produced in the house. Mean values in a row with uncommon superscript differed significantly.

Changes in nutrient content

Effect of growing days on nutrient changes in hydroponic wheat sprouts is shown in Table 6. The dry matter (DM) content of hydroponic wheat fodder was decreased remarkably ($p < 0.001$) with the advancement of growing days and it was more than 90% in initial wheat grain and less than 1/8th in day 8. The sharp reduction of DM content probably due to large uptake of water during germination of seed that causes remarkable increase in moisture content in hydroponic fodder (Fazaeli *et al*., 2012). This findings is highly in line with Kantale *et al*. (2017) who produced HWF in modern sprouting house and found 12.3% DM at day 8. Similarly, Shtaya (2004) found that the germination of wheat for 5 to 7 days resulted in a 17% loss of total DM while a 25% loss in DM of wheat after 12 days of sprouting. There is a consequent decline in the DM content with an increase in the fresh weight occurred during the sprouting process that is primarily attributed to the imbibition of water (leaching) and metabolic activities (oxidation) that diminishes the food reserves (mainly carbohydrate and energy) of the seed endosperm without any passable replenishment from photosynthesis by the young plant during little production cycle (Sneath and McIntosh, 2003; Al-Karaki and Al-Momani, 2011; Adjlanea *et al*., 2016). Dung *et al.* (2010b) also added that, photosynthesis commences nearby day-5 when the activation of chloroplasts occurred and this does not offer enough time for any significant DM accumulation in a 7-day sprout.

Again, organic matter (OM) content of wheat seed (98 g/100g DM) at day 0 reduced to

97g/100g DM at 8th day of sprouting (<0.001). Similarly, Naik *et al.* (2015) reported that in OM content of hydroponically produced maize fodder was declined 1% due to sprouting of 8 days. These decreasing trends may be due to catabolism of starch to fermentable carbohydrates which gives support to the metabolism and energy requirement of growing fodder for respiration and cell wall synthesis during the sprouting process (Naik and Singh, 2013; Naik *et al*., 2015).

Table 4. Correlation between morphological parameters and cost of production

Parameters	Biomass yield (kg)	Plant height (cm)	Root length (cm)	Root numbers (no.)	Cost of production (BDT.)
Biomass yield (kg)					
Plant height (cm)	0.989 **				
Root length (cm)	0.983 **	0.995 **			
Root numbers (no.)	0.891 **	0.890 **	0.893 **		
Cost of production (BDT.)	0.873 **	0.857 **	0.862 **	0.946 **	

*** indicates significant at p < 0.01.*

The crude protein (CP) content of the wheat grain was 13g/100g DM at day 0 and which was not vary (p > 0.05) up to the day 1 of hydroponic sprouting. With the advancement of sprouting days, CP content of the fodder increased simultaneously and around 7% more CP was found at day 8 than the day 0 (p < 0.001). The probable reason for gradual increasing of CP content in fodder may be due to reducing of dry weight through respiration during the sprouting process increase the CP content (Naik *et al*., 2015). However, difference in CP content between two consecutive days from 4th to 8th day was non-significant, which is similar to Dung *et al*. (2010a) who did not found any statistical difference in CP content between two successive days of hydroponic fodder. In the present analysis, the CP content of hydroponic wheat was greater than that of machine-grown wheat sprout (16%) reported by Kantale *et al*. (2017) and hydroponic maize fodder (14%) found by Naik *et al*. (2015).

The ether extract (EE) content of wheat seed was 1.7% and increased significantly (p<0.001) at day 1. The highest (2.7 g/100g DM) EE content of wheat fodder on 8th day which was 1 g more than that of day 0. This result is highly comparable with Kantale et al. (2017) who observed 1% increase in EE content due to sprouting of wheat. However, the variation in EE content between two consecutive days (e.g. day 1-2, 3-4, 5-6, 7-8) were found statistically similar (p > 0.05) over the study period. The increase in the EE content probably be due to the high content of chlorophyll at that particular stage (Islam *et al*., 2016). Similarly, Naik *et al*. (2015) found 1% increase in EE content of the hydroponic fodder and mentioned that might be attributed to the rise of

Table 5. Analysis of regression in morphological parameters with biomass yield and production cost

Response	Predictors	CoE	SE CoE	p-value	R^2
Biomass yield (kg)	Constant	1.07	0.07	<0.001	97.85
	Plant height (cm)	0.42	0.06	<0.001	
	Root length (cm)	0.08	0.09	0.358	
	Root numbers (no.)	0.04	0.02	0.120	
Cost of production / kg (BDT)	Constant	18.5	0.634	<0.001	91.05
	Biomass yield (kg)	1.83	0.503	<0.001	
	Plant height (cm)	0.98	0.356	0.057	
	Root length (cm)	0.57	0.415	0.175	
	Root numbers (no.)	1.29	0.115	<0.001	

CoE, Coefficient; SE CoE, Standard error of coefficient.

structural lipids and chlorophyll production corresponds to plant growth. According to Al-Saadi and Al-Zubiadi (2016) chemical compositions were significantly higher in green fodder than that of the grain.

The crude fiber (CF) content of the sprouted wheat showed an increasing trend with sprouting period and was highest (4.7g/100g) on 8th day (p=0.000) and the CF content of hydroponic wheat fodder wheat seed was 2.9g/ 100g. The CF content of 7th day hydroponic fodder was statistically similar with 8th day. In this study, it is noticeably visible that CF content was increased with the growing stages of plant maturity of hydroponic wheat fodder. This might be due to the effect of successive cell wall concentration with the increasing stages of maturity. This is in line with Naik *et al*. (2015) who mentioned that the synthesis of structural carbohydrates, such as cellulose and hemicellulose increases the CF during wheat sprouting process. Kantale *et al*. (2017) recorded 2 times more CF content in

Table 6: Changes of nutrient content (g/100g DM) of hydroponic wheat fodder with the advancement of

Day	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	p-value
DM (% of fresh)	90.30^{a} ±0.40	62.43^{b} ±0.49	40.27^{c} ± 1.35	32.44^{d} ± 0.40	26.93^{e} ± 0.06	21.42^{f} ± 0.32	17.18^{g} ± 0.82	14.88^{h} ± 0.00	14.19^{h} ± 0.84	0.000
OM	97.71^{a} ±0.02	97.65^{ab} ±0.02	97.61^{bc} ±0.07	97.52^{c} ±0.01	97.38^{d} ±0.03	97.29^{e} ±0.01	97.17^{f} ±0.03	97.07^{g} ±0.04	97.04^{g} ±0.01	0.000
CP	13.20^{g} ±0.03	13.85^{g} ±0.13	15.02^{f} ±0.06	17.17^{e} ±0.25	17.52^{de} ±0.40	18.14^{cd} ±0.10	18.92^{bc} ±0.05	19.70^{ab} ±0.71	19.83^{a} ±0.35	0.000
EE	1.67^{g} ±0.06	1.84^{f} ±0.01	1.98^{ef} ±0.04	2.14^{de} ±0.05	2.15^{d} ±0.13	2.33^{c} ±0.05	2.51^{b} ±0.01	2.66^{ab} ±0.04	2.70^{a} ±0.03	0.000
CF	2.90^{g} ±0.05	3.30^{f} ±0.01	3.41^{ef} ±0.02	3.50^{e} ±0.02	3.66^{d} ±0.05	3.90^{c} ±0.02	4.11^{b} ±0.05	4.57^{a} ±0.07	4.68^{a} ±0.03	0.000
NFE	79.94^{a} ±0.12	78.67^{b} ±0.15	77.20^{c} ±0.07	74.72^{d} ±0.22	74.05^{d} ±0.43	72.92^{e} ±0.04	71.62^{f} ±0.06	70.14^{g} ±0.78	69.82^{g} ±0.33	0.000
Ca	0.09^{f} ±0.01	0.09^{ef} ±0.01	0.10^{e} ±0.01	0.12^{d} ±0.01	0.13^{cd} ±0.01	0.13^{c} ±0.01	0.15^{b} ±0.01	0.16^{ab} ±0.01	0.17^{a} ±0.01	0.000
P	0.52^{g} ±0.01	0.58^{f} ±0.01	0.61^{e} ±0.01	0.64^{d} ±0.01	0.67^{c} ±0.01	0.71^{b} ±0.01	0.73^{b} ±0.01	0.77^{a} ±0.01	0.77^{a} ±0.01	0.000
Mg	0.14^{c} ±0.01	0.13^{c} ±0.01	0.14^{c} ±0.01	0.14^{c} ±0.01	0.15^{bc} ±0.01	0.15^{bc} ±0.01	0.17^{ab} ±0.01	0.18^{a} ±0.0^{a}	0.18^{a} ±0.01	0.000
Ash	2.29^{g} ±0.02	2.35^{fg} ±0.02	2.39^{ef} ±0.07	2.48^{e} ±0.01	2.62^{d} ±0.03	2.71^{c} ±0.01	2.83^{b} ±0.03	2.93^{a} ±0.04	2.96^{a} ±0.01	0.000

growth

DM, dry matter; OM, organic matter; CP, crude protein; EE, ether extract; CF, crude fibre; NFE, nitrogen-free-extract; Ca, calcium; P, phosphorus; Mg, magnesium; Means within the same row bearing different superscript differ significantly. Mean values in a row with uncommon superscript differed significantly.

Table 7. Correlation between different nutrient content (g/100g DM) of hydroponic wheat fodder

Variables	DM	OM	CP	EE	CF	NFE	ASH	Ca	P	Mg
DM										
OM	0.854**									
CP	0.931**	0.950**								
EE	0.899**	0.967**	0.963**							
CF	0.860**	0.971**	0.929**	0.972**						
NFE	0.924**	0.972**	0.995**	0.981**	0.961**					
ASH	0.854**	1.000**	0.950**	0.967**	0.971**	0.972**				
Ca	0.885**	0.986**	0.968**	0.990**	0.969**	0.985**	0.986**			
P	0.936**	0.972**	0.970**	0.993**	0.976**	0.987**	0.972**	0.981**		
Mg	0.753**	0.923**	0.863**	0.921**	0.902**	0.892**	0.923**	0.929**	0.897**	

*** indicates significant at $p < 0.01$.*

Table 8. Correlation between nutrient contents (g/100g DM) and morphological parameters of hydroponic wheat fodder

Variable	Biomass yield (kg)	Plant height (cm)	Root length (cm)	Root number (nos,)
DM	0.862**	0.866**	0.866**	0.968**
OM	0.989**	0.989**	0.988**	0.889**
CP	0.948**	0.959**	0.964**	0.932**
EE	0.982**	0.974**	0.967**	0.912**
CF	0.986**	0.975**	0.966**	0.882**
NFE	0.974**	0.978**	0.979**	0.932**
ASH	0.989**	0.989**	0.988**	0.989**
Ca	0.986**	0.991**	0.985**	0.904**
P	0.978**	0.980**	0.976**	0.949**
Mg	0.931**	0.927**	0.905**	0.787**

*** indicates significant at $p < 0.01$.*

hydroponic wheat fodder grown in hi-tech sprouting housing system than that of wheat grain and this probably attributed to the increase in the number and size of cell walls for the synthesis of structural carbohydrates (Naik *et al*., 2015). In case of hydroponic barley, CF content was 3.5% at day 0 and increased 6.5 to 8% in days 5 and 8, respectively (Abd Rahim and Omar, 2015).

The nitrogen free extract (NFE) content of wheat seed decreased during the sprouting process to its minimum level on 8^{th} day (69.82 %) from 79.94% in wheat seed (Day 0). Such a decreasing trend in NFE content might be due to the use of endosperm storage mainly carbohydrate and energy in seed respiration of plant cells and its other metabolic activity. But it was decreased at non-significant rate between the days of 3 to 4 and 7 to 8. Kantale *et al.* (2017) also noted a decrease (10g/100g DM) in NFE content of hydroponic wheat fodder. Seed soaking leads to the activation of enzymes solubilisation and digestion of endosperm stored starch to simple sugars that delivers a substrate for the young growing plant for metabolic activities to produce energy, giving off carbon dioxide and water. This loss of carbon dioxide leads to a decrease in NFE content (Emam, 2016).

Table 9. Analysis of regression in morphological parameters with nutrient contents

Response	Predictors	Coefficient	SE Coefficient	p-value	R^2
DM	Constant	91.92	6.52	0.000	94.30
	Biomass yield (kg)	-6.96	4.81	0.162	
	Plant height (cm)	4.05	3.70	0.286	
	Root length (cm)	-1.39	4.12	0.738	
	Root numbers (no.)	-9.37	1.10	0.000	
OM	Constant	97.784	0.034	0.000	98.46
	Biomass yield (kg)	-0.066	0.025	0.015	
	Plant height (cm)	-0.006	0.019	0.775	
	Root length (cm)	-0.031	0.022	0.169	
	Root numbers (no.)	-0.004	0.006	0.462	
CP	Constant	13.055	0.601	0.000	94.85
	Biomass yield (kg)	0.216	0.444	0.632	
	Plant height (cm)	-0.265	0.342	0.446	
	Root length (cm)	0.709	0.381	0.076	
	Root numbers (no.)	0.293	0.101	0.008	
EE	Constant	1.504	0.066	0.000	97.10
	Biomass yield (kg)	0.175	0.049	0.002	
	Plant height (cm)	0.010	0.038	0.786	
	Root length (cm)	-0.026	0.042	0.537	
	Root numbers (no.)	0.024	0.011	0.043	
CF	Constant	2.670	0.104	0.000	97.27
	Biomass yield (kg)	0.304	0.077	0.001	
	Plant height (cm)	0.041	0.059	0.498	
	Root length (cm)	-0.061	0.066	0.368	
	Root numbers (no.)	0.003	0.018	0.870	
Ash	Constant	2.216	0.034	0.000	98.46
	Biomass yield (kg)	0.066	0.025	0.015	
	Plant height (cm)	-0.006	0.019	0.775	
	Root length (cm)	0.031	0.022	0.169	
	Root numbers (no.)	-0.004	0.006	0.462	
NFE	Constant	80.555	0.643	0.000	97.27
	Biomass yield (kg)	-0.761	0.474	0.123	
	Plant height (cm)	0.209	0.365	0.574	
	Root length (cm)	-0.653	0.407	0.123	
	Root numbers (no.)	-0.315	0.108	0.008	
Ca	Constant	0.086	0.006	0.000	98.36
	Biomass yield (kg)	0.001	0.005	0.765	
	Plant height (cm)	0.006	0.004	0.131	
	Root length (cm)	-0.002	0.004	0.591	
	Root numbers (no.)	0.001	0.001	0.591	
P	Constant	0.504	0.017	0.000	98.59
	Biomass yield (kg)	0.023	0.014	0.109	
	Plant height (cm)	-0.001	0.11	0.921	
	Root length (cm)	0.005	0.11	0.650	
	Root numbers (no.)	0.012	0.002	0.000	
Mg	Constant	0.136	0.008	0.000	92.19
	Biomass yield (kg)	-0.002	0.007	0.795	
	Plant height (cm)	0.014	0.005	0.017	
	Root length (cm)	-0.014	0.005	0.019	
	Root numbers (no.)	-0.002	0.001	0.153	

The ash content of wheat seed at day 0 was 2.3 g and 0.7 g more ($p = 0.001$) at day 8 than that of the day 0. Similarly, hi-tech machine grown hydroponic wheat fodder contained 0.6g/100g DM more ash than that of wheat seed reported by Kantale *et al*. (2017). This findings highly in accordance with Naik et al. (2015) and who reported that total ash content was became double in hydroponic maize fodder than that of maize grain due to the decrease of organic matters contents during the sprouting process. However, ash content was similar ($p > 0.001$) between days of 0 to 1, 1 to 2, 2 to 3 and 7 to 8. Morgan *et al.* (1992) found that sprout ash content increased from 4th day of sprouting, corresponding with root extension which permitted mineral uptake. The sprout ash content increases more when nutrient solution is used rather than water which might be due to root absorption of minerals (Dung *et al*., 2010b).

Minerals like calcium (Ca), phosphorus (P) and magnesium (Mg) contents of wheat grain were meaningfully increased ($p < 0.001$) with the advancement of growing days. The higher percentages of Ca, Mg and P were found at day 8 than that of the other growing days, and these minerals were statistically not dissimilar ($p > 0.05$) between 7 and 8 days of growing. However, cereal sprouting makes the minerals more usable by chelating with protein (Shipard, 2005). Generally, changes in the hydroponics fodder's mineral content are primarily affected by the irrigated water type (Al-Ajmi *et al*., 2009; Fazaeli *et al*., 2011).

Correlation between proximate components of hydroponic wheat fodder is presented in Table 7.Dry matter content strongly negatively correlated ($p < 0.001$) with CP, CF, EE and ash contents whereas strong positive correlation exists between DM, OM and NFE content ($p < 0.001$). Crude protein content strongly positively correlated with CF, EE and ash contents, and negatively correlated with NFE and OM contents of fodder. Similarly, EE and CF contents negatively correlated with the NFE and OM content. Lorenz and D'Appolonia (1980) reported that sprouting of grain enhanced enzyme activity, a decrease of total DM, an improvement in total protein content, a shift in amino acid composition, a decline in starch content, increases in carbohydrates, a slight increase in EE and CF, and a slight increase in other vitamins and minerals. Correlation between the nutrient content and hydroponic wheat fodder morphology parameters are tabulated in Table 8.

It was found that DM content of hydroponic wheat fodder has a negative correlation ($p < 0.001$) with biomass yield, root length, plant height and root numbers. However, plant nutrient viz. CP, CF, EE and ash contents of hydroponic fodder have a strong positive correlation ($p < 0.001$) with biomass yield, root length, plant height and root numbers. On the other hand, morphological parameters were strongly negatively correlated ($p < 0.001$) with OM and NFE content wheat sprout.

Multiple regression analyses of nutrient contents of hydroponic wheat fodder at different days (response) in terms of morphological parameters (predictors) are presented in Table 9. Variability in responses is almost completely ($R^2 > 92\%$) covered by the predictors in all the regression models. It was observed that increase in each unit of root numbers decreased 9 unit of DM content ($p < 0.001$) and 0.3 unit of NFE content (0.008). Similarly, every unit biomass yield reduced OM content 0.07 unit ($p=0.015$). Around 0.3 unit of CP ($p = 0.008$) and 0.02 unit of EE ($p = 0.043$) content of HWF will be increased with the increase of each unit of root number. On the other hand, each unit of biomass yield of HWF increased 0.3 unit of CF ($p=0.001$) and 0.07 unit of ash ($p=0.015$), respectively.

Conclusions

Yield, morphology, nutrient content and production cost of hydroponic wheat fodder were varied significantly with the growing days in sprouting cycle. Considering these features, hydroponic sprout wheat was better for feeding animals at days 7 and 8 compared to the other days of production. Therefore, it is recommended that, wheat fodder as hydroponic up to 7-8 days may be a new source of feed for livestock, especially for dairy cattle. However, further study should be conducted regarding the changes of nutrient and morphological parameters of various grains and their comparison should be made with hydroponic wheat and their field level validation is needed.

Conflict of Interest

The authors declare that there is no conflict of interest.

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