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Research Article

Effects of Harvesting Age and Barley Varieties on Morphological Characteristics, Biomass Yield, Chemical Composition, and Economic Benefits under Hydroponic Conditions in Fogera District, Ethiopia

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The objectives of this study were to evaluate the effects of harvesting age at 6, 8, 10, and 12 days and four barley varieties HB-1307, Debark-1, Tila, and local varieties on morphological characteristics, biomass yield, chemical composition, and economic benefits under hydroponics in the Fogera district at Fogera National Rice Research and Training Center of Amhara Region, Ethiopia. The interaction effects of harvesting age and barley variety significantly influenced growth parameters of plant height, shoot length, leaf length, and overall chemical composition ($P < 0.05$). All morphological characteristics were significantly different ($P < 0.01$) among harvesting ages, and the stem weight, leaf to stem ratio (LSR), and number of leaves per plant were not significantly influenced ($P > 0.05$) by the different barley varieties. The highest plant height (21.26 cm) and crude protein (CP) content (21.39%) were obtained from Debark-1 at 12 days of harvesting. The highest fresh fodder biomass yield, 203.50 t/ha, and dry matter (DM) yield, 36.21 t/ha, were obtained at 12 days of harvesting. In the case of harvesting age, all morphological parameters increased with the progress harvesting age, except for the LSR and DM content. The highest net return of 2,923,002.25 ETB/ha was obtained from Debark-1 at the 12 days harvesting age, and the lowest 941,201.13 ETB/ha was obtained for the Tila variety at the six days of harvesting age. From the study, it can be concluded that based on fresh fodder biomass yield, DM yield, CP, and economic benefits, Debark-1 was the recommended barley variety on the 12-day harvesting age, followed by HB-1307, local, and Tila barley varieties.

1. Introduction

The livestock sector significantly contributes to the Ethiopian economy, contributing about 40% of the agricultural GDP, 20% of the national GDP, and 20% of foreign earnings [1]. However, productivity is low due to several factors, such as inefficient management, poor infrastructure, poor marketing and credit facilities, feed shortages in quality and quantity, and health constraints [2]. About 60%–70% of livestock productivity is affected by feed [3]. Particularly in the Fogera district, the major feeds are communal grazing and rice straw, but this rice straw has poor nutritional value. At a minimum, green fodder supplementation is essential to improve rumen function in cattle [4].

Livestock holders face various problems in feed production, such as land and water scarcity, manure required, long growing season (45–60 days), fencing to prevent forage from wild animals, and natural climate [5]. To combat quality and quantity of livestock feed shortage, hydroponic green fodder production is advisable. Hydroponics is emerging as an alternative and advanced technology due to its being environmental friendly, producing constant feed supply all year round, and supporting commercialization livestock production [6]. Globally, hydroponic forage production started in the 18th century in the Netherlands, Germany, and Australia. Kenya

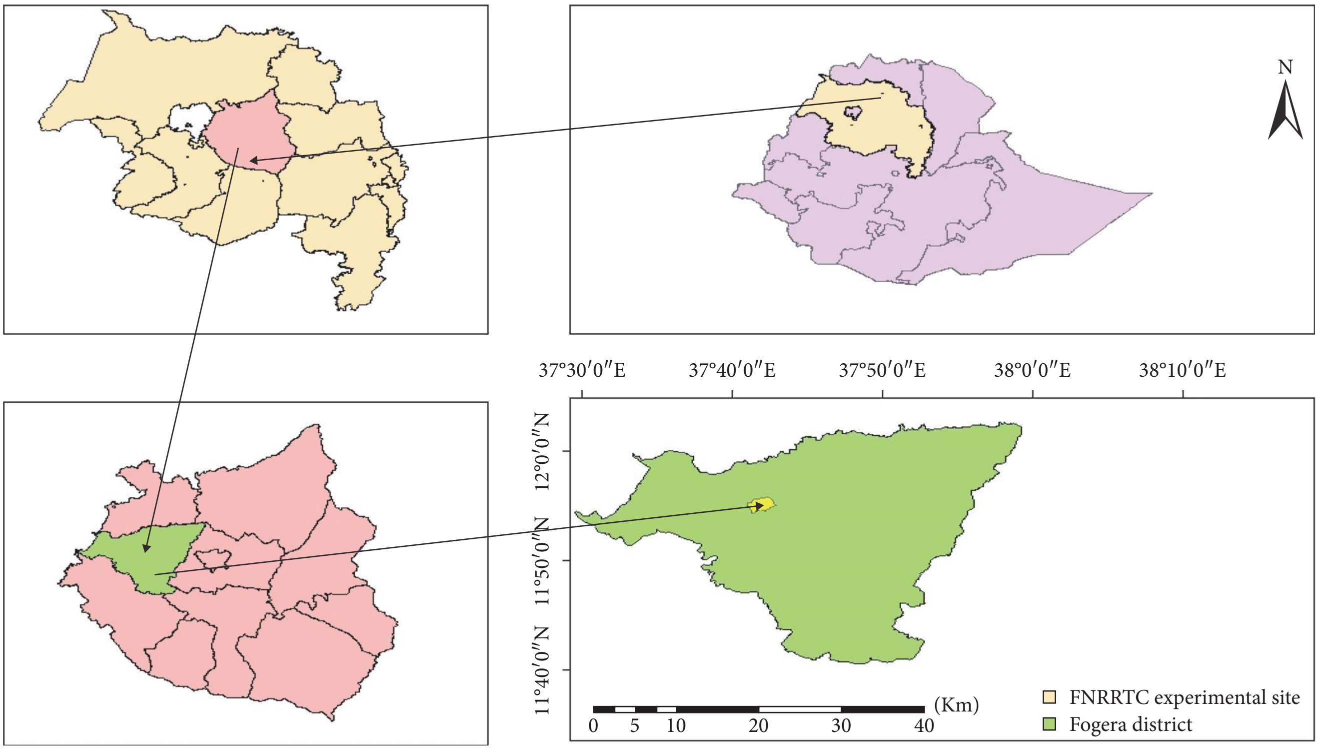

Figure 1: Map of the study area.

was the first country in Africa to use hydroponics for milk, meat, and poultry production [7].

Although it is not widely employed in Ethiopia, hydroponic has been utilized in certain areas of the country, such as Mekelle in the Tigray region [8]. Hydroponics cultivation significantly impacted animal production and productivity and it can meet the nutritional needs of growing animals and ensures stable production of green fodder throughout the year [9]. This year round availability of the green fodder will minimize the livestock feed gap of Ethiopia as reported by [10]. Additionally, to exploit the milk production potential of the crossbred dairy cows, the emerging urban and peri-urban dairy production in the country demanding hydroponic fodder production. The facilities for hydroponic green fodder production are almost available in the local [11] and it can be widely adapted in the production system where the cereal seeds are economically available. After tef, maize, sorghum, and wheat, barley is the fifth crop grown in the country and region. In addition to the landrace, improved barley varieties have been grown in the area for food production. Hydroponic green fodder production study conducted in Ethiopia using local barley landraces but limited for the improved once [12]. Evaluation of green fodder production and its chemical composition because of harvesting age and varietal difference could be an important step of agronomic practices the producers should understand before the wider application.

The availability of improved feeds, agro-industrial byproducts, and green feed is limited. The district's livestock holders faced a feed problem in cost, quality, and quantity. There is a lack of information on the production and utilization of hydroponic green feed in the study district. The objective of the study was to evaluate the effect of harvesting age and barley (*Hordeum vulgare*) varieties on the morphological characteristics, biomass yield, chemical composition, and economic benefits under hydroponic conditions in the Fogera district, Amhara Region.

2. Materials and Methods

2.1. Study Areas. The study was conducted under a temperature of 26°C in the Fogera district at Fogera National Rice Research and Training Center (FNRRTC), South Gondar Zone, Amhara Region, Ethiopia (Figure 1). The experimental site is geographically located at 13°16°56°7′ latitude North and 35°70°74′ longitude East; at an altitude of 1,811 m above sea level.

2.2. Description of Experimental Material. Materials used during the experiment were different barley grain, plastic trays, plastic buckets, a hydroponic unit, nutrient solution, scissors, a measuring cylinder, a highland water sprayer, weighing balance, a meter, wood, nail, white plastic, gunny bag, beaker, mesh, and four barley variety (HB-1307, Debark-1, Tila, and local).

2.3. Hydroponic Shed, Shelf, and Tray Preparation. Green fodder is produced in a hydroponic greenhouse measuring (10 × 6 × 3 m) in length, width, and height, respectively. The shed had 3 m in height and 10 m in length. The entire wall of the greenhouse was covered by mesh and white plastic. From the 3 m high of walls, only a 0.5 m length was covered by a mesh used for ventilation and lighting. The shelf had a

2%–3% slope, and 8–10 holes were on one side of the plastic tray to allow excess water to drain. The internal shelf structure was made from wooden studs with three shelves in a north–south orientation. Each shelf had 3.4 m in length and 1 m wide, and the 48 hydroponics trays were stacked vertically. The distance between each shelf and each tray was 50 and 10 cm, respectively. Each hydroponic tray size was 35 × 25 × 7 cm.

2.4. Seed Collection, Treatment, and Preparation. Experimental barley seeds (HB-1307 and Debark-1) were obtained from Gondar Agricultural Research Center, the Tila variety from Adet Agricultural Research Center, and local varieties from the Woreta market in the Fogera district. For the hydroponic production of green fodder, barley seeds with a germination rate of more than 98% were employed. Dirt and other foreign materials were screened, and then the seeds were washed with tap water two tothree times to control mold formation. Additionally, the seeds were sterilized by soaking them in a 1% bleach solution (Berekina) for 30–60 min in order to avoid the growth of mold. After 2 hr, the seeds were again washed twice with tap water. Each seed was soaked in fresh water for 12 hr. After 12 hr, the water was drained, and the seeds were left without water for at least 1 hr for respiration. After the respiration time, the seeds were stored in a plastic bag. Here, all the experimental seeds were allowed for germination for 36 hr. Afterward, the germinated seeds were transplanted into trays to produce green fodder.

2.5. Nutrient Solution Preparation and Application. The hydroponic nutrient solution contained six macronutrients of Ca, K, N, Mg, S, and P, with composition of 89.20, 81.90, 75.10, 1.80, 20.80, and 43.20 g, respectively, and seven micronutrients such as Zn, Fe, Cl, Cu, Mn, Bo, and Na at a level of 3.20, 1.80, 0.50, 0.40, 0.01, 0.10, and 0.10 ppm, respectively. The nutrient solution was diluted at a ratio of 5 ml of nutrient solution with 10 ml of water. The hydroponic trays were irrigated at the affixed rate of 500.025 ml diluted nutrient solution containing 500 ml tap water and 0.025 ml nutrient solution three times a day (early morning, midday, and late afternoon), spraying for 20 s.

2.6. Experimental Design and Treatments. The study used a randomized complete design (RCD) with three replications in 4 × 4 factorial arrangements of two factors (barley variety and harvesting age). Each factor included four different levels of barley varieties (HB-1307, Tila, Debark-1, and local) as well as harvesting ages (6, 8, 10, and 12 days). There were a total of 48 experimental trays in the three replicates on the shelf, each of which included 16 treatments.

2.7. Sowing, Watering, and Harvesting of Hydroponic Barley Fodder. Different barley seeds were sown in the trays on July 2, 2022. The plastic trays were placed on the shelves and the treatments were randomly assigned to the trays. The seeding rate of barley seed was adopted 4.5 kg/m^2 according to the recommendation [13], and 393.75 g of barley seeds were sown at 1.5–2 cm seed depth. To keep the seedlings moist, a constant watering of 500.25 ml/tray three times a day was employed. Constant watering was carried out using 500.25 ml/tray three times a day to keep the seedlings moist. Then, the biomass of barley varieties were harvested for the respective harvesting stages. During harvesting, approximately 350 g of green feed and 20 plants per tray were randomly selected and measured morphological parameters. Harvesting was done manually, and scissors were used to separate the plants.

2.8. Data Collection

2.8.1. Morphological Data Collection. Fresh fodder biomass yield was calculated by adding the weight of the forage and the tray and subtracting the weight of the tray. The number of leaves per plant (NLPP) was counted and their mean values were computed. Plant height (PH): was measured from the tray level to the top of the longest leaf using a ruler. Shoot length (SL): was measured from the seed to the top of the longest leaf using a ruler. The NLPP was manually counted from each tray by hand. Leaf length (LL): was measured from the branch to the tip of the longest leaf. Leaf weight (t/ha): during harvesting, 20 plant leaves were cut with a razor blade and weighed using a weighing balance. Then, the fresh leaf weight obtained on the tray area was converted to tone/ha. Stem weight (t/ha): during harvesting, 20 plants' stems were cut with a razor blade and weighed using a weighing balance. Then calculate the fresh stem weight obtained on the tray area and convert it to tone/ha.

Root mass weight (t/ha): during harvesting, 20 plant roots were cut with a razor blade and weighed using a weighing balance. Then calculate, the fresh root mass weight obtained on the tray area was converted to tone/ha. Leaf to stem ratio (LSR): fresh leaf and stem weights were weighted separately from all harvesting ages. The leaf and stem were dried by air in the shade for 36 hr at 26°C temperature. Then, the ratio was calculated by dividing the leaf's dry weight by stem dry weight. The value of conversion factors was the ratio of produced green fodder to the initial planted seed weight. Dry matter (DM) yields (DMY) were calculated by:

$$\text{DMY(t/ha)} = 10 \times \text{TFW} \times \text{SSDW}/\text{HA} \times \text{SSFW}, \quad (1)$$

whereas 10 = constant for conversion of yields in kg/m^2 to tone/ha, TFW = total fresh weight from the harvested area (kg), SSDW = subsample dry weight (g), HA = harvested area (m^2), and SSFW = subsample fresh weight (g).

2.8.2. Chemical Composition Analysis. Samples were air-dried for 36 hr under natural airflow at a temperature of 26°C, and partial DM was determined by drying the fodder samples at 65°C in an air-forced oven for 72 hr. Feed chemical composition measurements such as DM, crude protein (CP), and ash were analyzed via [14]. Nitrogen content was determined by the Kjeldahl approach. The CP was calculated as N* 6.25. Ash was determined by igniting at 550°C

Table 1: Mean plant morphological characteristics and dry matter yield of barley as affected by variety and harvesting age.

Sources of variation	NLPP	LW (t/ha)	SW (t/ha)	RMW (t/ha)	LSR	FFBY	CF	DMY (t/ha)
Harvesting age								
6	1.00^{c}	2.40^{d}	0.91^{d}	21.80^{b}	2.63^{a}	137.97^{d}	3.05^{d}	25.12^{d}
8	1.00^{c}	3.72^{c}	1.65^{c}	24.87^{a}	2.21^{b}	163.26^{c}	3.62^{c}	30.25^{c}
10	1.55^{b}	4.76^{b}	2.36^{b}	25.73^{a}	2.01^{b}	179.25^{b}	3.97^{b}	32.86^{b}
12	1.85^{a}	6.46^{a}	3.56^{a}	26.18^{a}	1.93^{b}	203.50^{a}	4.51^{a}	36.21^{a}
Mean	1.35	4.34	2.12	24.64	2.2	170.99	3.78	31.11
SEM	0.03	0.22	0.14	1.02	0.13	5.67	0.12	1.20
Variety								
HB	1.37	4.66^{a}	2.3	25.05^{a}	2.18	177.53^{ab}	3.94^{ab}	32.01^{ab}
D	1.33	4.89^{a}	2.16	27.27^{a}	2.46	187.15^{a}	4.15^{a}	34.32^{a}
T	1.38	3.75^{b}	1.86	21.20^{b}	2.08	148.42^{c}	3.28^{c}	26.82^{c}
L	1.3	4.04^{b}	2.17	25.07^{a}	2.06	170.87^{b}	3.78^{b}	31.29^{b}
Mean	1.35	4.34	2.12	24.64	2.2	170.99	3.78	31.11
SEM	0.11	0.48	0.32	0.93	0.15	8.08	0.18	0.50
Sig. level								
Harvesting age	****	***	***	**	**	***	***	***
Variety	ns	***	ns	***	ns	***	***	***
Interaction	ns	ns	ns	ns	ns	ns	ns	ns

[abcd]means followed by different superscript letters in the column differ at $P<0.05$; ns = not significant; ** = significant at $P<0.01$; *** = significant at $P<0.001$. NLPP, number of leaf per plant; LW, leaf weight; SW, stem weight; RMW, root mass weight; LSR, leaf to stem ratio; FFBY, fresh fodder biomass yield; CF, conversion factor; SEM, standard error of mean; DMY, dry matter yield; ns, nonsignificant; HB, HB-1307; D, Debark-1; T, Tila; L, local.

overnight for 6 hr. The neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were determined by [15]. The feed chemical analyses were done at Bahir Dar University Animal Nutrition Laboratory.

2.9. Economic Analysis. The economic feasibility of different barley varieties was determined by a partial budget analysis of the method [16]. Economic analysis was performed to determine the most economical harvesting age of different barley varieties in hydroponic green fodder production. Total variable costs (TVC) included the costs of barley seed, nutrient solution, chemical (detergent), and labor costs. Hydroponically produced barley fodder has been marketed in DM bases, and the sales price of hydroponic fodder was taken as gross income. Net return (NR) was calculated as gross return (GR–TVC). NR was calculated by the difference between GR and TVC (NR = GR–TVC).

2.10. Data Analysis. Data were subjected to analysis of variance (ANOVA) using (GLM), (SAS, 9.2). Duncan's multiple range test was used for mean comparisons at $\alpha = 0.05$. The model was:

$$\mathrm{Yij} = \mu + \mathrm{HAi} + \mathrm{Vj} + (\mathrm{HAi} \times \mathrm{Vj}) + \mathrm{eij}, \quad (2)$$

where Yij = dependent variables (morphological characteristics, yield data, and chemical composition), μ = overall mean, HAi = Effect of i^{th} harvesting age, Vj = effect of j^{th} varieties, HAi × Vj = interaction effect (harvesting age and barley varieties), eij = random error.

3. Results and Discussion

3.1. Agronomic Characteristics of Different Barley Varieties under Hydroponic Conditions. The current study showed that most plant morphological characteristics and DMY were not significantly affected ($P>0.05$) by the interaction effect of harvesting age and different barley varieties (Table 1). But, PH, and LL were significantly affected ($P<0.001$) by the two factors' interaction (Table 2). All the measured agronomic and yield parameters were significantly ($P<0.001$) affected by the main effects of harvesting age. Different barley varieties showed significant differences ($P<0.001$) in all growth parameters except the NLPP, stem weight, and LSR.

A higher PH was noted in all barley varieties on the 12 days of harvest and shorter PHs on the 6 days. PHs of Debark-1, HB-1307, local, and Tila barley varieties in the 12 days of harvesting (21.26, 21.10, 18.33, and 16.63 cm) were higher than the findings reported by Bulcha et al. [12] for hydroponically grown black (14.72 cm), Mosno (18.34 cm), and white barley (14.76 cm). The current result of hydroponic barley harvested on the 8 days 12.24 cm PH was below the hydroponically grown cereal crops height of 14.0 cm [17]. Also, the current investigation (12.24 cm) PH at 8 days harvesting was within the range of 11–30 cm [6, 8]. The difference in PH of different barley varieties and harvesting age in the current study might be attributed to growth stages, genetic makeup, adaptability of different barley varieties to specific environments, temperature, and management during the experiment. Similar to this finding, a significant variety and harvesting age interaction effect was found for maize fodder grown hydroponically [18].

Longer SLs were shown in HB-1307, Debark-1, and local barley variety on the 12 days of harvesting (17.21, 16.41, and

Table 2: Mean plant height (PH), shoot length (SL), and leaf length (LL) of the four barley varieties harvested at four maturity stages (in days).

Harvesting age (days)	Varieties	PH	SL	LL
6	HB	9.4^{g}	7.33^{j}	5.06^{fg}
	D	9.2^{g}	7.19^{j}	4.93^{g}
	T	9.13^{g}	7.16^{j}	4.93^{g}
	L	8.43^{g}	6.53^{j}	4.56^{g}
	Mean	9.04	7.06	4.87
	SEM	0.58	0.57	0.46
8	HB	12.06^{f}	9.55^{hi}	6.99^{de}
	D	14.73^{e}	12.26^{ef}	9.25^{c}
	T	10.83^{f}	9.18^{i}	6.03^{ef}
	L	11.33^{f}	10.4^{ghi}	6.33^{e}
	Mean	12.24	10.35	7.11
	SEM	0.39	0.81	0.27
10	HB	14.1^{e}	10.96^{bcd}	7.76^{d}
	D	17.43^{bc}	14.58^{cd}	9.25^{c}
	T	15.36^{de}	11.75^{efg}	7.81^{d}
	L	18.13^{b}	14.96^{bcd}	9.6^{c}
	Mean	16.26	13.07	8.61
	SEM	0.58	0.66	0.32
12	HB	21.1^{a}	17.21^{a}	12.3^{a}
	D	21.26^{a}	16.41^{ab}	10.63^{b}
	T	16.63^{cd}	13.28^{de}	9.06^{c}
	L	18.33^{b}	15.06^{bc}	$9.7b^{c}$
	Mean	19.33	15.50	10.42
	SEM	0.25	0.24	0.28
Significance level				
Harvesting age		***	***	***
Variety		***	***	***
Interaction		***	***	***

^{abcdefghij}means followed by different superscript letters in the column differ at $P<0.05$; *** = significant at $P<0.001$; SEM, standard error of mean; HB, HB-1307; D, Debark-1; T, Tila; L, local.

15.06 cm), respectively. All barley varieties had shorter SLs at 6 day harvesting. The current study SL harvested on 12 days was 15.50 cm was lower than 20 cm [17]. Differences in the shoot growth potential of different barley varieties and harvesting age might be in sprouting days, genetic makeup, and management. The later the harvesting age, the plant will continue to grow the SL. Similar to this study, Jemimah et al. [19] observed that for various hydroponic fodders (yellow maize, Horse Gram, Sun Hemp, and Jowar), the SL increased as the harvesting age increased.

Longer LLs of 12.30 cm and 10.63 cm were recorded on HB-1307 and Debark-1 barley varieties, respectively, on the 12 days of harvesting. LL was increased along with the advancement in harvesting age as supported by Lamidi et al. [18]. The higher LL was obtained on all barley varieties on the 12 days of harvesting than on the 6, 8, and 10 days. The lowest LL, on the other hand, was obtained on the 6 day harvesting for HB-1307, Debark-1 Tila, and local barley varieties (5.06, 4.93, 4.93, and 4.56 cm), respectively. The current investigation was similar to [5] in that late harvesting ages can produce a longer LL. The differences in LL in the different barley varieties and harvesting ages might be attributed to the growth stage, genetic makeup, temperature, and management.

Similar with other morphological parameters, the highest NLPP (1.85) was obtained at 12 days of harvesting, while the lowest number of leaves (1) per plant was on the 6 and 8 days of harvesting. The number of leaves is crucial for increasing biomass production and improving the nutritional value of the green fodder [20]. The difference in the NLPP at the harvesting ages might be due to the variation in the growth stage, management, and temperature. During the early harvesting age on the 6 and 8 days, plants initially develop only shoots and stem, whereas, on the 10 and 12 days of harvesting, they tend to grow leaves for further photosynthesis.

The current result leaf weight at the 6, 8, 10, and 12 days of harvesting (2.40, 3.72, 4.76, and 6.46 t/ha), respectively, which was above the [12] reported dry leaf weights on the 6, 8, 10, and 12 days harvesting was (0.23, 0.34, 0.63, and 1.21 t/ha), respectively. The highest leaf weight, 6.46 t/ha, was obtained on the 12 days of harvesting as compared to other harvesting ages. As harvesting age increases, photosynthesis continues, and the growth of plant leaf weight also increases. This implies a longer harvesting age may bring a higher plant leaf growth and higher leaf weight was recorded on the 12 days of harvesting. Similar to this finding, [12] reported that the hydroponically grown varieties of green fodder barley varied in leaf weight. Higher leaf weights (4.89 and 4.66 t/ha) were obtained at Debark-1 and HB-1307 varieties, and a lower leaf weight (3.75 t/ha) was recorded in the Tila barley variety. There was no significant difference ($P>0.05$) in leaf weight between HB-1307 and Debark-1 barley and Tila and local barley varieties. Current results different barley variety leaf weight of HB-1307, Debark-1, Tila, and local barley (4.66, 4.89, 3.75, 4.04 t/ha), respectively, were higher than that reported by Bulcha et al. [12] for black barley (0.96 t/ha), Mosno (2.48 t/ha), and white barely (0.98 t/ha) leaf weights. Variations in leaf weight among the different barley varieties could be due to the differences in the genetic makeup, management, and greenhouse temperature of hydroponically grown cereals.

On the 6, 8, 10, and 12 harvesting ages, the mean dry stem weights 0.91, 1.65, 2.36, and 3.56 t/ha were obtained, respectively. The late harvesting age will help the plant use nutrients in the barley seed, and the plant continues to increase in stem weight. Variations in stem weight at different harvesting ages might be to the plant stem growth stage, management, and temperature during the experiment. The absences of significant variation among barley varieties in stem weight signifies that barley has a similar ability in stem growth and stem-weight maturation to this fodder production technology.

The root mass weight recorded on the 6 (21.8 t/ha), 8 (24.87 t/ha), 10 (25.73 t/ha), and 12 (26.18 t/ha) days of harvesting were comparable with the finding reported by Bulcha et al. [12] reporting for root mass weight at the 6, 8, and 10 days were (23.84, 22.23, and 21.09 t/ha),

Table 3: Mean chemical composition of the four barley varieties harvested at four maturity stages (in days).

HA (days)	V	DM (%)	Quality traits (DM%)				
			Ash	CP	NDF	ADF	ADL
6	HB	92.70^{ab}	3.88^{gh}	15.78^{hi}	38.39^{e}	13.25^{g}	3.97^{h}
	D	92.81^{a}	3.79^{h}	17.15^{ef}	37^{e}	12.84^{g}	5.21^{efg}
	T	92.73^{a}	4.57^{b}	14.99^{i}	38^{e}	15.85^{e}	5.36^{def}
	L	92.36^{abcd}	3.47^{i}	16.15^{gh}	38.5^{e}	15.1^{ef}	6.08^{cd}
	Mean	92.65	3.92	16.01	37.97	14.26	5.15
	SEM	0.30	0.04	0.29	0.56	0.36	0.33
8	HB	92.46^{abc}	4.32^{cde}	17.63^{de}	41.6^{d}	15.05^{ef}	4.80^{fg}
	D	92.13^{cde}	3.75^{h}	18.66^{c}	41.5^{d}	14.65^{f}	6.02^{cd}
	T	92.49^{abc}	4.44^{bcd}	16.59^{fgh}	42.75^{d}	15.75^{e}	4.99^{fg}
	L	92.47^{abc}	4.33^{cde}	16.76^{efg}	45^{bc}	14.46^{f}	4.78^{fg}
	Mean	92.38	4.21	17.41	42.71	14.97	5.14
	SEM	0.15	0.09	0.43	0.88	0.27	0.19
10	HB	92.25^{bcde}	4.58^{b}	18.82^{c}	46.1^{b}	17.25^{d}	4.53^{gh}
	D	92.36^{abcd}	4.11^{ef}	21.09^{a}	43.3^{cd}	18.7^{c}	5.25^{efg}
	T	92.11^{cde}	4.60^{b}	18.85^{c}	46.18^{b}	19.5^{c}	7.33^{b}
	L	91.89^{ef}	4.24^{def}	16.60^{fgh}	45.9^{b}	17.15^{d}	7.22^{b}
	Mean	92.15	4.38	18.84	45.37	18.15	6.08
	SEM	0.14	0.09	0.24	0.73	0.42	0.28
12	HB	91.87^{ef}	4.28^{cdef}	19.90^{b}	47.15^{b}	21.3^{b}	6.29^{c}
	D	91.96^{def}	4.06^{fg}	21.39^{a}	45.5^{bc}	21.25^{b}	5.94^{cde}
	T	91.56^{f}	5.06^{a}	19.80^{b}	50^{a}	23.36^{a}	7.44^{b}
	L	90.86^{g}	4.47^{bc}	18.37^{cd}	51.7^{a}	23.25^{a}	8.44^{a}
	Mean	91.56	4.46	19.86	48.58	22.29	7.02
	SEM	0.23	0.06	0.34	0.77	0.26	0.19
Sig. level							
Harvesting age		***	***	***	***	***	***
Variety		**	***	***	***	***	***
Interaction		*	***	***	*	***	***

^{abcdefghi}means followed by different superscript letters in the column differ significantly at $P<0.05$; * = significant at $P<0.05$; ** = significant at $P<0.01$ *** = significant at $P<0.001$; DM, dry matter; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; V, variety; HA, harvesting age; HB, HB-1307; D, Debark-1; T, Tila; L, local; CV, coefficient of variance; SEM, standard error of mean.

respectively. But, a difference was visible at 12 days of harvesting (12.18 t/ha) [12]. Their root mass was significantly affected ($P<0.05$) by variety. A higher root mass weight (27.27 t/ha) was recorded in the Debark-1 varieties, and a lower root mass weight (21.20 t/ha) was recorded for the Tila variety. The variations in root mass weights by harvesting age and the barley varieties might be attributed to the growth stage, genetic makeup, management, and the greenhouse temperature during the experiment.

The highest (2.63 t/ha) LSR was recorded on the 6 days of harvesting, and the lowest (1.93 t/ha) was recorded on the 12 days of harvesting age. As the harvesting age increased, the LSR decreased due to the development and maturation of the stem more than the leaf. Additionally, Buxton [21] provides evidence for it, stating that as plants mature, their LSR typically declines. It can be concluded that LSR declined sharply as the harvesting ages increased. The LSR difference in the case of harvesting age might be the growth stage, management, and temperature in the greenhouse.

The mean fresh fodder biomass yield on the 6, 8, 10, and 12 days of harvesting (137.97, 163.26, 179.25, and 203.50 t/ha) were higher than the work of [12] on the 6, 8, 10, and 12 days of harvesting (41.98, 43.80, 51.09, and 61.88 t/ha), respectively. The highest fresh fodder biomass yield on the 12 days of harvesting depends on growth parameters of PH, stem development, NLPP, LL, and root development. Similar to the current study, [12] found that as harvesting age increased, the fresh yield of barley grown hydroponically increased. Debark-1 had the highest fresh forage yield (187.15 t/ha) as compared to the other three experimental barley varieties. Higher fresh fodders biomass yield at Debark-1 might be due to the small size of the seed, which helps obtain many plants per hectare. This indicates that the Debark-1 barley variety could be preferred for hydroponic forage production. Bottom of FormThe average green fodder yield of HB-1307, Debark-1, Tila, and local barley (177.53, 187.15, 148.42, and 170.87 t/ha) were above according to Bulcha et al. [12] who reported to the fresh biomass yield of

68.49, 104.77, and 68.50 t/ha for black, Mosno, and white barley, respectively. Variations of fresh biomass yield among different harvesting ages and barley varieties might be due to differences in the growth of leaf stem and root, management, temperature, different barley varieties, light, moisture, the growth rate of LSR, and barley seed size, which agreed with the finding reported in the literature [22–24].

A higher conversion factor was recorded at the 12 days of harvesting (4.51%), while a lower conversion factor was recorded at the 6 days of harvesting (3.05%). A higher conversion factor indicates the increment of the fresh biomass yield to grain seed ratio. The current results were comparable according to Al-Ajmi et al. [25] who reported 2.76–3 times green fodder per kg of barley seed used for hydroponic fodder production at the 6 days harvesting age. Debark-1 barley had more conversion factor (4.15%) than HB-1307, local, and Tila (3.94%, 3.28%, and 3.78%), respectively. The conversion factors in the current study were consistent with the report of [26] who reported variation in conversion factor in different seed varieties, light intensity, water quality (pH), seeding density, and temperature. The current result conversion factor agreed well with Moony [9] who reported that the conversion factor ratio depended on management, grain quality, a nutritious solution, temperature, humidity, and the number of seeds on each tray.

The mean DMY of fodder recorded in the current study at 6, 8, 10, and 12 days of harvesting (25.12, 30.25, 32.86, and 36.21 t/ha), respectively, were more than the values (24.03, 23.14, 21.34, and 13.31 t/ha) [12]. DMY from 7 to 9 kg of fresh forage corresponding to 0.9–1.1 kg of DM [25] were below the current finding of 7–9 kg of green fodder production (1.26–1.62 kg DM). The lower DMY on the 6 days of harvesting (25.12 t/ha) might be due to the increased photosynthesis, which in turn reduces the accumulation of DM because photosynthesis commences around day five [22]. The mean DMY (32.01, 34.32, 26.82, and 31.29 t/ha) for HB-1307, Debark-1, Tila, and local, respectively, which were higher than the work of [12] for black (23.30 t/ha), Mosno (18.78 t/ha), and white barley (19.85 t/ha). Variations of DMY in harvesting age and barley variety were the difference in fresh fodder produced, genetic makeup, management, growth stage, and temperature.

3.2. Chemical Composition of Different Barley Varieties under Hydroponic Condition. For the studied chemical compositions, the interaction effect of various harvesting ages and barley varieties were significant ($P < 0.01$), as shown in Table 3. DM content was significantly influenced ($P < 0.05$) by the interaction effect of harvesting age and barley varieties. On the 6 days harvesting, the barley varieties Debark-1, Tila, and HB-1307 were found to have higher DM contents, 92.81%, 92.73%, and 92.70%, respectively. On the 12 days of harvest, the local, Tila, and HB-1307 barely varieties produced lower DM contents of 90.86%, 91.56%, and 91.87%, respectively. The reduction in DM content during the 12 days of harvesting might be due to the diminishing of the starch substance since starch is catabolized to solvent sugars for supporting the digestion system and vitality prerequisite of the developing plants for breathing [6, 11]. Other studies [12, 13, 27] also confirmed that the DM from hydroponically grown barley green fodder reduced as the harvesting stage increased. The difference in DM content of the interaction effect (different barley varieties and harvesting age) in the current result might be due to growth stages (length of sprouting days), genetic makeup, temperature, and management during the experiment.

The Tila variety displayed a higher ash content at all harvesting ages than the other experimental barley. The higher ash fractions (5.06%, 4.60%, 4.44%, and 4.57%) were obtained for the Tila variety at the 12, 10, 8, 6 days harvesting, respectively. The lower (3.47%, 3.79%, and 3.88%) ash contents were recorded for local, Debark-1, and HB-1307 on the 6 days of harvesting, respectively. The highest ash (5.06%) at Tila on the 12 days harvesting exceeded from 3.6% ash contents reported by [28]. The ash contents of hydroponic barley fodders were increased due to the progress of harvesting ages. This was supported by different studies [12, 13, 18, 27] who reported that ash content increased during forage plant growth.

Also, the ash content in local barley (3.47%) at the 6 days of harvesting agreed with the ash content of 3.4% [28] but was lower than 3.9% [12]. The difference in the mineral content of hydroponic barley fodder might be attributed to length of sprouting days, morphological development, and climatic conditions [29]. The current results were similar according to Morgan and Hunter [30], the root elongation increased the ash content of sprouts with increasing harvesting age, allowing for mineral uptake. Differences in ash content in the current investigation on the harvesting age and different barley varieties may be genetic makeup, management, temperature, and level of harvesting stages.

The CP content was significantly ($P < 0.001$) affected by the main effects of harvesting age, barley variety, and their interaction. The forage's CP content is the critical parameter for the forage evaluation since it is an essential nutrient required by ruminant animals [23]. The highest CP contents were recorded on the 12 and 10 days of harvesting for Debark-1 and HB-1307, and Tila at the 12 days harvesting (21.39, 21.09, 19.90, and 19.80 CP%), respectively. In comparison, the lowest CP content was recorded at Tila, HB-1307, and local varieties on the 6 days of harvesting (14.99, 15.78, and 16.15 CP%), respectively. In the current study, CP content increased in late harvesting, agreed with other studies [12, 13, 27]. Similarly, Ndaru et al. [31] and Lamidi et al. [18] reported that the CP contents for maize fodder were increased as harvesting ages were delayed.

According to Bulcha et al. [12] report, 16.4% of CP content was lower as compared with the current study (18.84%) at the 10 days of harvesting. CP levels increased from the 6 days of harvesting (14.99 CP%) for the Tila variety and on the 12 days of harvesting (21.39 CP%) for Debark-1. Sprouting has been reported for the increased CP content of hydroponic fodder and the increasing number of leaves as harvesting time increased could also be reflected in the increased CP content [8, 12, 31]. Differences in the protein content of hydroponic barley fodders may be due to differences in

Table 4: Economic analysis of hydroponically barley fodder as affected by interaction effect (harvesting age and barley varieties).

Variety (V)	Parameters	Harvesting age (HA)			
		HA6	HA8	HA10	HA12
HB	TVC	901,998.88	961,998.50	1,021,998.13	1,081,997.75
	Gross return	2,544,000.00	3,012,000.00	3,283,000.00	3,965,000.00
	Net return	1,642,001.13	2,050,001.50	2,261,001.88	2,883,002.25
D	TVC	901,998.88	961,998.50	1,021,998.13	1,081,997.75
	Gross return	2,805,000.00	3,357,000.00	3,562,000.00	4,005,000.00
	Net return	1,903,001.13	2,395,001.50	2,540,001.88	2,923,002.25
T	TVC	901,998.88	961,998.50	1,021,998.13	1,081,997.75
	Gross return	1,843,200.00	2,058,400.00	2,273,600.00	2,406,400.00
	Net return	941,201.13	1,096,401.50	1,251,601.88	1,324,402.25
L	TVC	901,998.88	961,998.50	1,021,998.13	1,081,997.75
	Gross return	2,396,000.00	3,160,000.00	3,456,000.00	3,505,000.00
	Net return	1,494,001.13	2,198,001.50	2,434,001.88	2,423,002.25

V, varieties; HA, harvesting age; HB, HB-1307; D, Debark-1; T, Tila; L, local; TVC, total variable cost; TC, total cost; GR, gross return; NR, net return; ETB, Ethiopian birr.

genetic composition, harvesting stage, management, and temperature during the study. In line with the current study, according to Sneath and McIntosh [32] confirmed that CP levels can be influenced by growing conditions.

The NDF content was significantly influenced ($P < 0.05$) by the interaction effect of harvest age and barley variety. The highest NDF contents for all different barley varieties were obtained during the 12 days of harvesting. In contrast, the lower NDF content was recorded for HB-1307, Debark-1, Tila, and local barley varieties at the 6 days harvesting (38.39%, 37%, 38%, and 38.5% NDF), respectively. Overall, HB-1307 and Debark-1 were lower in NDF content compared to Tila and local barley varieties.

According to Singh and Oosting [33], feeds with a NDF value of less than 45% are classified as high quality, while those falling between 45% and 65% are classified as medium quality, and higher than 65% are classified as low quality. The current study NDF content on the 6, 8, and 10 days harvesting (37.9%, 42.71%, and 45.37% NDF), respectively were categorized in high quality, while all varieties on the 12 days harvesting the NDF were in medium quality feed. The mean NDF content for all barley varieties met the high-quality feed standards. This confirms that hydroponic barley feed produced in the current study is classified as high to medium-quality fodder and is expected to be high in animal intake. The current study was consistent with [12, 13, 18] reported that the NDF content increased with delayed harvesting age. The difference in NDF contents of different barley varieties and harvesting ages in the current study may be due to growth stage, genetic makeup, temperatures, and variations in management during the experiment.

ADF content was significantly differed ($P < 0.0001$) between harvesting age, barley variety, and their interaction. Higher ADF contents were recorded in Tila and local barley variety at the 12 days of harvesting (23.36 and 23.25 ADF%), respectively and the lowest were obtained from Debark-1 and HB-1307 at the 6 days of harvesting (12.84 and 13.25 ADF%), respectively. According to Owens [34], ADF values in the 17%–32% range are classified as high-quality feed. Therefore, the current study's 14.26–22.29% ADF contents were categorized in high-quality green feed.

The cell wall accumulation of ADF percentage was raised due to the increasing growth stage, according to Fazaeli et al. [13]; which was in line with the current investigation. In the late harvesting age, ADF content increased due to structural cell wall components increasing as the plant matured because photosynthesis components are converted to structural components at the expense of soluble carbohydrates [18, 35]. Variations in ADF content may be due to differences in genetic makeup, management, temperature, and harvesting stage.

ADL content was highly influenced ($P < 0.0001$) by harvesting age, barley variety, and their interaction. The highest ADL content was recorded in local barley at the 12 days harvesting (8.44%), whereas the lowest mean ADL content was in HB-1307 at the 6 days harvesting (3.97%). Higher ADL was recorded in the 12 days of harvesting than in other harvesting ages. Variations in ADL content may be due to the differences in genetic makeup, management, and different harvesting age. Cellulose accumulation in the cell wall was reported to increase with delayed harvesting age [13].

3.3. Economic Analysis. A partial budget analysis of different barley varieties grown under the hydroponic condition at different harvesting ages and their interaction are presented in Table 4. The TVC, including the purchase price of barley seed, nutrient solution, detergent (chemicals), and labor cost, was recorded during the experiment. Finally, the produced hydroponic barley feeds were sold and obtained gross income in (ETB), calculating the NR as follows.

Economic analysis showed that the net benefits gained from Debark-1 at 12 days of harvesting were higher than that of other varieties and harvesting ages. In the current study, the Debark-1 barley variety at the 12 days of harvesting achieved the highest NR (2,923,002.25 ETB/ha), followed by HB-1307 at 12 days of harvesting with a NR (2,883,002.25 ETB/ha). On the other hand, the Tila barley variety at 6 days of harvesting has the lowest net benefits (1,494,001.13 ETB/ha). The 12 days harvesting age was appropriate to be economically and affordable for future hydroponically grown barley green fodder production in this technology. Though limited economic evaluation of hydroponic fodder in Ethiopia, Elmulthum et al. [36] in Saudi Arabia reported that hydroponic fodder are more economical than the conventional forage production.

4. Conclusions

From the study, it can be concluded that based on fresh fodder biomass yield, DM yield, CP, and economic benefits, Debark-1 was best perfomer on the 12 day harvesting age, followed by HB-1307, local, and Tila barley varieties. Employing the fodder from Debark-1 and HB-1307 could be recommended for animal performance evaluation for further study.

Data Availability

Data will be available from the first author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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